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A GENERAL PROCEDURE FOR OBTAINING VELOCITY VECTOR FROM A SYSTEM--ETC(U)
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Monterey, California

A General Procedure for Obtaining Velocity Vector from a System of High Response Impact Pressure Probes

D. Adler and R. P. Shreeve

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A technique to measure a high frequency, repetitively pulsating flow field is presented. Two impact tube probes and a Kiel probe, all with pressure transducers mounted in their tips are used. Five readings are required to identify a velocity vector at a point.

In this report the technique, the numerical procedure and the computer program used are described.

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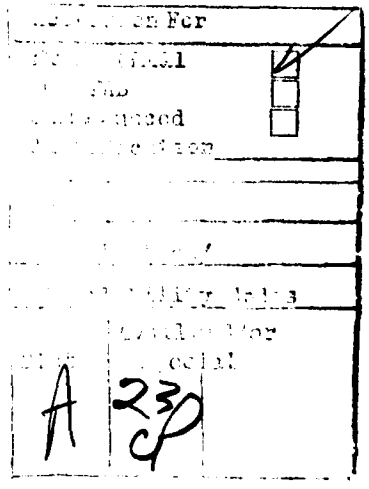
D. Adler and R. P. Shreeve



Contents

Notation

Cp - Pressure coefficient defined in eq. (3)

α - Yaw angle relative to laboratory space

ϕ - Pitch angle relative to laboratory space

P_t - Total pressure

P_s - Static Pressure

α_{rp} - Yaw angle relative to probe axis

ϕ_{rp} - Pitch angle relative to probe axis

P_p - Pressure indicated by the probe

α_p - Yaw setting of the probe

ϕ_p - Pitch setting of the probe

Subscripts

I, II, III, IV } relating to probe positions shown in figure 3

A relating to A type probe

B relating to B type probe

Lo lowest value in an array

rp relative to the probe axis

Up highest value in an array

Notation of PENPTS

DD - denominator in the subsequent line of the program

HT - penetration height (Cp of a calibration surface)

IR - a flag with a value of either 1 or 2 to identify first or second penetration point. This flag also controls return of values to calling program or subroutine

IB - a flag indicating the location of the last rectangle in the band checked for a penetration point. It prevents repetition of the scanning in the 103 Do loop

NX - number of X values in the calibration surface grid (∝ values of the calibration surface)

NY - number of Y values in the calibration surface grid (values of the calibration surface)

X(I) - X values in the grid

XM - value of X at point B (fig. 5)

XR(I) - two values of X returned by the subroutine as results

XS - currently calculated value of X which is the present result and is later stored in XR(I)

Y(J) - Y values in the calibration grid

YC - intermediate value used in the subsequent line of the program

YG - the Y position of the penetrating line*

Z(I.J)- Values of the Z = Cp calibration surface above grid points

ZX - value of Z either at point A or point C (see figs. 5, 6 and 7)

ZM - value of Z at point B

---

* It should be pointed out here that the penetrating line is parallel to the X axis at a height HT = Cp above the X,Y plane and at a distance YG from the X axis on the X,Y plane

Notation of INTSCS

AA	-	constant defined in eq. 8
AB	-	constant defined in eq. 9
ARIN	-	ordinate at which scanning starts
ARLO	-	lowest ordinate of calibration surface (as a condition it must be identical for all calibration surfaces used)
ARM1	-	ordinate measured relative to probe 1 (the probe belonging to the first curve Cp = const.)
ARM2	-	ordinate measured relative to probe 2 (the probe belonging to the second curve Cp = const)
ARP1	-	setting ordinate of probe 1
ARP2	-	setting ordinate of probe 2
ARRES (1)	-	abscissa value returned to INTSCS from PENPTS
ARUP	-	highest ordinate of calibration surface (as a condition it must be identical for all calibration surfaces used)
AR2R	-	ordinate relative to laboratory space
AR2RJ	-	ordinate relative to laboratory space of previous scan
BA	-	constant defined in eq. 8
BB	-	constant defined in eq. 9
DAR	-	ordinate step for scanning
HT1	-	penetration height of calibration surface of probe 1 (Cp of probe 1)
HT2	-	penetration height of calibration surface of probe 2 (Cp of probe 2)
IEPS	-	a flag which is equal to 2 when the calculation is carried out as shown in fig. 11, otherwise it is equal to 1. (This information is required in the main program and is returned to it)

ISL	- a flag which is equal to 10 if one of the left hand side results returned from PENPTS is 1000.0 (i.e., is not a penetration point). Otherwise it is equal to 1
ISR	- a flag which is equal to 10 if one of the right hand side results returned from PENPTS is 1000.0 (i.e., is not a penetration point). Otherwise it is equal to 1
K	- a flag indicating whether the first or the second intersection is evaluated
N1	- number of abscissas in calibration surface grid (fig. 4)
N2	- number of Ordinates in calibration surface grid (fig. 4)
RES1(K)	- evaluated and returned abscissa of intersection
RES2(K)	- evaluated and returned ordinate of intersection
R1	- radius in fig. 11 for probe 1
R2	- radius in fig. 11 for probe 2
RAIL	- abscissa of point AIL in fig. 9 or 10
RAIR	- abscissa of point AIR in fig. 9 or 10
RAJL	- abscissa of point AJL in fig. 9 or 10
RAJR	- abscissa of point AJR in fig. 9 or 10
RBIL	- abscissa of point BIL in fig. 9 or 10
RBIR	- abscissa of point BIR in fig. 9 or 10
RBJL	- abscissa of point BJL in fig. 9 or 10
RBJR	- abscissa of point BJR in fig. 9 or 10
X1(I)	- abscissas of calibration surface of probe 1 or its transformation as determined by calling statement in main program
X2(I)	- abscissas of calibration surface of probe 2 or its transformation as determined by calling statement in main program

X3(I) - abscissas of calibration surface of probe 1 or its transformation as determined by calling statement in main program

X4(I) - abscissas of calibration surface of probe 2 or its transformation as determined by calling statement in main program

Y1(I) - ordinates matching X1(I)

Y2(I) - ordinates matching X2(I)

Y3(I) - ordinates matching X3(I)

Y4(I) - ordinates matching X4(I)

Z1(I,J) - values of Cp_{rp} for X1(I) and Y1(I)

Z2(I,J) - values of Cp_{rp} for X2(I) and Y2(I)

Z3(I,J) - values of Cp_{rp} for X3(I) and Y3(I)

Z4(I,J) - values of Cp_{rp} for X4(I) and Y4(I)

Notation of Main Program VDR

A - variables in library routine IXCLOK used to evaluate computation times

ALF - values of α returned to VDR from INTSCS

ALFA - α input when experiment simulation is carried out

ALFC - α_{rpIII}

ALFCN - new value of α_{rpIII} for next iteration

ALFD - α_{rpIV}

ALFDN - new value of α_{rpIV} for next iteration

ALF1 - α_I

ALF2 - α_{II}

ALF3 - α_I

ALF4 - α_{III}

AM - mach number

CPA - Cp_{rpI}

CPB - Cp_{rpII}

CPC - Cp_{rpIII}

CPD - Cp_{rpIV}

EPSPS - relative difference between present static pressure and its value in the previous iteration

EPSPSG - convergence criterion (on the static pressure)

FALF - final α value (at convergence)

FPHI - final ϕ value (at convergence)

IA50 - a flag in IXCLOK

IA60 - a flag in IXCLOK

ICOPS - number of PS corrections carried out to ensure the Cp's are in calibration range

IEPS - a flag governing the convergence criterion returned from INTSCS

IEPS1 - a flag governing the convergence criterion for probes I and II

IEPS2 - a flag governing the convergence criterion for probes I and III

IIT - number of iterations on p_s

ISCAN - number of static pressure scans from initial static pressure guess upwards

IXCLOK - system subroutine for computation time evaluation

NOCOPS - a flag which when equal to 1 causes static pressure corrections to be carried out such that Cp's are always inside calibration range, and when equal to 2 cause these corrections to be skipped

NOSIM - a flag which when equal to 1 causes the program to simulate velocity measurement experiments and when equal to 2 causes the program to reduce measured data

NX - number of calibration surface matrix abscissa's, α values (must be identical for all calibration surface matrices used)

NY - number of calibration surface matrix ordinates, ϕ values (must be identical for all calibration surface matrices used)

PDYN - dynamic pressure

PHI - value of ϕ returned to VDR from INTSCS

PHIB - ϕ_{rpII}

PHII - ϕ input when experiment simulation is carried out

PHI1 - ϕ_{rpI}

PHI2 - ϕ_{rpII}

PHI3 - ϕ_{rpI}

PHI4 - ϕ_{rpIII}

PPA - signal of probe in position I

PPB - signal of probe in position II

PPC - signal of probe in position III

PPC - signal of probe in position IV

PS - static pressure

PSIN - initial guess of static pressure

PSN - new value of static pressure for next iteration

PSC - corrected static pressure

PST - memorized corrected static pressure

PT - total pressure measured

RELXPS - relaxation factor for convergence on the static pressure

VIRTIM - virtual computation time

XA - abscissas of calibration surface matrix of probe A

XAX - transformed abscissas of calibration surface matrix of probe A

XB - abscissas of calibration surface matrix of probe B

XBX - transformed abscissas of calibration surface matrix of probe B

XPC - yaw setting of position III

XPD - yaw setting of position IV

XRIN - α value at which scanning starts

XRLU - lowest α value of calibration surface (as a condition it must be identical for probes A and B)

XRUP - highest α value of calibration surface (as a condition it must be identical for probes A and B)

YA - ordinates of calibration surface matrix of probe A

YAX - transformed ordinates of calibration surface matrix of probe A

YB - ordinates of calibration surface matrix of probe B

YBX - transformed ordinates of calibration surface matrix of probe B

YPA - pitch setting of probe A

YPB - pitch setting of probe B

YRIN - ϕ value at which scanning starts

YRLO - lowest ϕ value of calibration surface (as a condition it must be identical for probes A and B)

YRUP - highest ϕ value of calibration surface (as a condition it must be identical for probes A and B)

ZA - Cp_{rpA} values of probe A

ZAX - transformed Cp_{rpA} values of probe A

ZAMAX - maximum of ZA array

ZAMIN - minimum of ZA array

ZB - Cp_{rpB} values of probe B

ZBX - transformed Cp_{rpB} values of probe B

ZBMAX - maximum of ZB array

ZBMIN - minimum of ZB array

Introduction

Experimental knowledge of the flow field generated by rotating turbo impellers is of prime importance in the research and development of turbomachinery. It is essential for the refinement of design methods, for the development of new flow models which include secondary flow and tip clearance effects, and particularly for the verification of new computer codes developed to calculate the flow through rotating blade rows.

In recent years laser velocimeter techniques have been applied successfully to measure the flow both inside and downstream of rotors. (Ref. 1 for example). It has become clear however, that the laser techniques are only reliable in the hands of experienced investigators. A window which remains clean is essential, and seeding is usually required. Laser techniques do not measure the pressure field and usually can only measure two components of the velocity unless the axis of the laser is tilted. Difficulty is also encountered when measuring close to walls. Hence there are reasons to consider alternative techniques, particularly if they are simpler to apply routinely in stationary turbomachinery passages. Furthermore, the achievement of redundancy in measuring the flow field behind the impeller is itself a worthwhile goal. The present

work deals with the application of a particular system of small high response pressures probes at the exit of an impeller.

Measurements behind an impeller, in the stationary bladeless gap, are simpler to make than measurements within the rotating passages. Transducer probes can be installed through the stationary machine casing and the data transmitted without resort to slip rings or rotary transformers. The sensor is not subjected to the centrifugal field or to the vibration of the rotor. However, the flow to be measured is then fluctuating at blade-passing frequency and any system of sensors must be calibrated for a wide range of possible Mach number, pitch angle, yaw angle and pressure variation - and yet must be capable of the necessary frequency response.

In Ref. 2, a method was described for using two semiconductor pressure probes together with the technique of synchronized sampling, to obtain the distribution of the velocity vector downstream of a rotor. The geometries of the two probes, designated Type A and Type B, and their installation in the compressor annulus are shown in Fig 1. It was argued that, in principle, by rotating the probes in yaw about their tips and controlling the sampling of the data from each probe to be at the same position in the rotor frame, the system of two separate probes could be used to acquire data at a point in the periodic flow

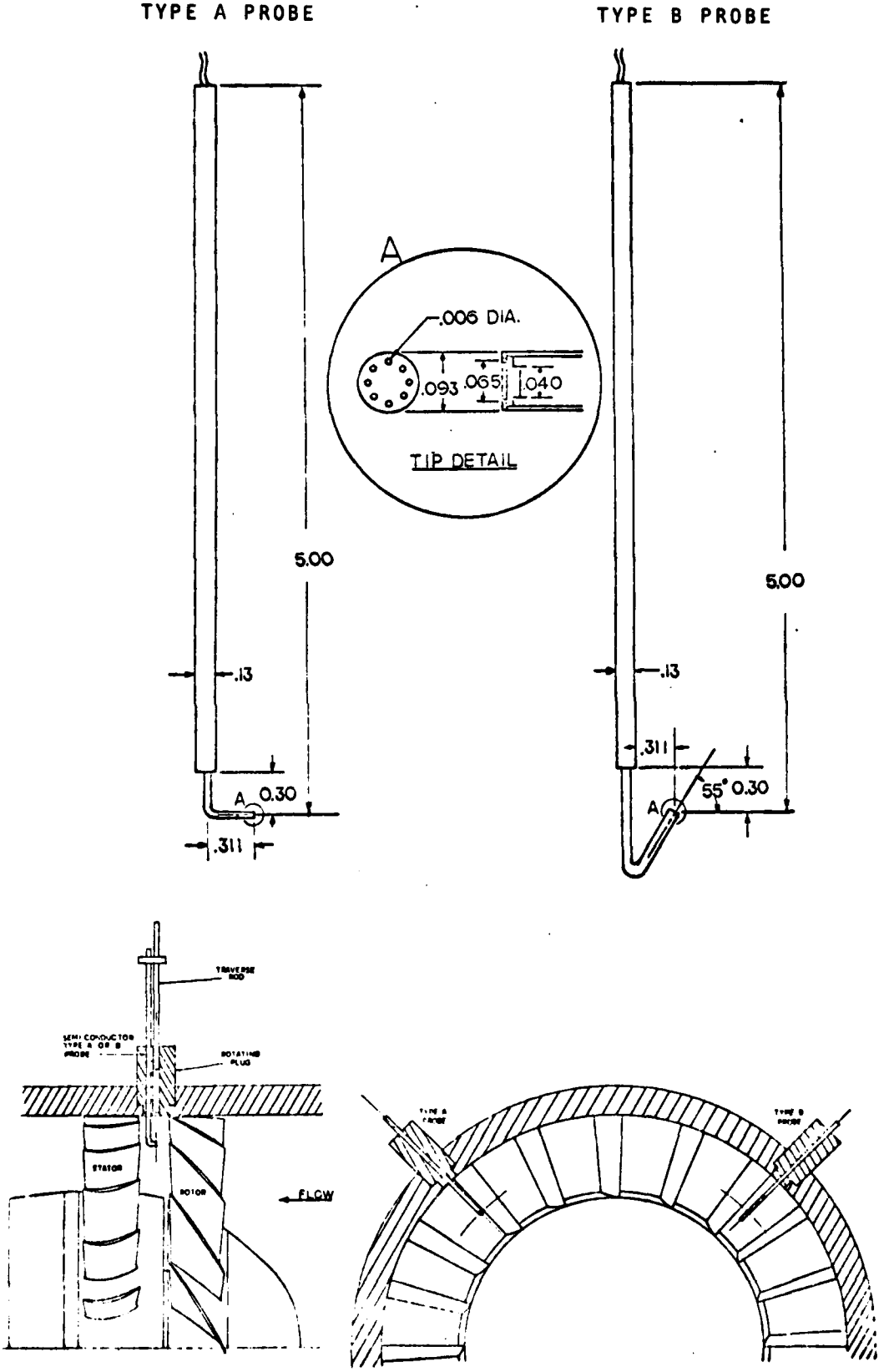


FIGURE 1. TYPE A AND TYPE B PROBES AND COMPRESSOR INSTALLATION.

from the rotor, corresponding to data normally obtained from the multiple sensors of four- or five hole pneumatic probes when measuring velocity in steady flows. The technique promised the use of probes having the simplest geometry and thus avoided the large size, expense and unreliability of multiple sensor probes which incorporate multiple semi-conductor transducers (Ref. 3). Because of the simple sensor tip geometry (that of a cylinder at incidence to the flow) the unsteady response was likely to be as good as could be expected of any single physical sensor.

The two-probe technique is strictly applicable only to periodic flows. However, data obtained on successive rotations of the rotor can be averaged to eliminate fluctuations which are not periodic. This was shown to be effective in tests reported in Ref. 2 in which a single Type A probe was used to establish the peripheral blade-to-blade distribution of flow yaw angle.

In order to obtain velocity from the pressure measurements which can be obtained from the two probes, the steady response characteristics must first be established in calibration tests carried out in a known, controlled, uniform flow. Second, a method of applying the calibration to measurements made in an unknown flow must be devised. In the present method two different approaches have been followed. In Ref. 4, a technique is given for representing

and applying the probe calibration analytically. When first applied the method gave surprisingly good accuracy (1 - 2%) since the method required that the probes had characteristics which could be well represented analytically. This in turn required that the probe tips be geometrically precise, a feature which was not present in the first generation of probes.

A second, more general approach is reported here, wherein the calibration of each probe is represented by a two-dimensional array of pressure coefficients. The application of the calibration given in this form, in an unknown flow required the development of special numerical procedures. The purpose of the present report is to document the analysis and the Fortran program developed to apply the method.

In its present form, the method does not require that the calibration "Surfaces" be symmetrical about any axis or be expressed in analytical form, but does require that the pressure coefficient be independent of Mach number. The latter restriction could undoubtedly be removed by introducing additional iterative steps. Further, in the present method only five measurements have to be taken to determine uniquely a velocity vector at a point. Throughout the report, the Fortran program notation has been used to describe the physics and equations involved in the solution.

Mathematical model

Assume the A and B type probes of ref. [1] (see also fig. 1) to be immersed in a three-dimensional steady flow field.* The pressure response of each of these probes in given gas is functionally described by four variables as:

$$P_p = P_p\,(\alpha, \phi, P_T, P_S) \tag{1}$$

If a pressure coefficient is defined as

$$Cp_{rp} = \frac{P_p - P_s}{P_T - P_s} \tag{2}$$

The calibration surface of each probe is given in the general case in form of a matrix of values of Cp, where

$$Cp_{rp} = Cp_{rp}(\alpha_{rp}, \phi_{rp}) \tag{3}$$

The pressure coefficient defined in this way has only a second order dependence on Mach and Reynolds numbers in the range of

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* For our purpose, using the synchronized sampling, the flow field behind the impeller is steady, although the probes require a high speed response because of fluctuations.

$0 < Ma < 0.7$ in turbulent flows (Ref. 2), so that, to first order their influence is neglected in writing eq. (3).

If the type A probe is rotated about its axis into three different positions (i = I, III, IV) readings are taken, and the type B probe is fixed in position II and a single reading is taken, the following four equations can be written.

$$Cp_{Ai} = \frac{P_{pAi} - P_S}{P_T - P_S} = Cp_{Ai}(\alpha,\phi)$$
$$Cp_{BII} = \frac{P_{pBII} - P_S}{P_T - P_S} = Cp_{BII}(\alpha,\phi) \qquad (4)$$

it should be pointed out here, to avoid misunderstanding that α and ϕ are defined in a coordinate system relative to the machine axis and not relative to the probe axis. In the set of four equations (4) there are four unknown quantities, namely: α, ϕ, P_T and P_S. These are the quantities to be evaluated using the measured data. Together with the stagnation temperature they define the flow field uniquely. The four equations, resulting from the four measurements, should be sufficient to determine the four unknown quantities.

But the problem is complicated by three facts:

1) The calibration surfaces are not generally known in analytical form.
2) The calibration surfaces are double valued in α and ϕ i.e., for a given Cp and α there exist two ϕ values, or for a given Cp and ϕ there are two α values which satisfy eq. 3.

3) As a result of the measurement the value of P_p rather than of C_p is determined.

Since the calibration surfaces are not given in a simple analytical form the solution has to be numerical. An iterative procedure is required because P_p and not C_p values are measured. First P_s and P_T have to be guessed to yield C_p values, knowing the four measured values of P_p, and using eq. 4. The guess is then iteratively corrected to converge on the solution. However, convergence of the iterative procedure is complicated because of the double valued nature of the calibration surfaces.

This method of iteration shown in Fig. 2 was attempted initially for the evaluation of a measured point. In practice the initially suggested procedure converged in some cases and diverged in others, depending on the values, and signs of α and ϕ. This was not surprising as convergence on two variables is not likely to be a simple matter. However, in order that the measurement technique be useful, convergence on the correct solution for a general set of measurements, is absolutely necessary. In practice, this can certainly be achieved if one of the two iteration variables is obtained by measurement. Since the static pressure is a difficult quantity to measure even in a steady flow field, only the stagnation pressure measurement need be considered. It is possible that the time-varying stagnation pressure could be measured with a suitably designed Kiel probe. Data would then be taken by synchronized sampling from the fixed Kiel probe, from the type A probe rotated into two positions, and from the

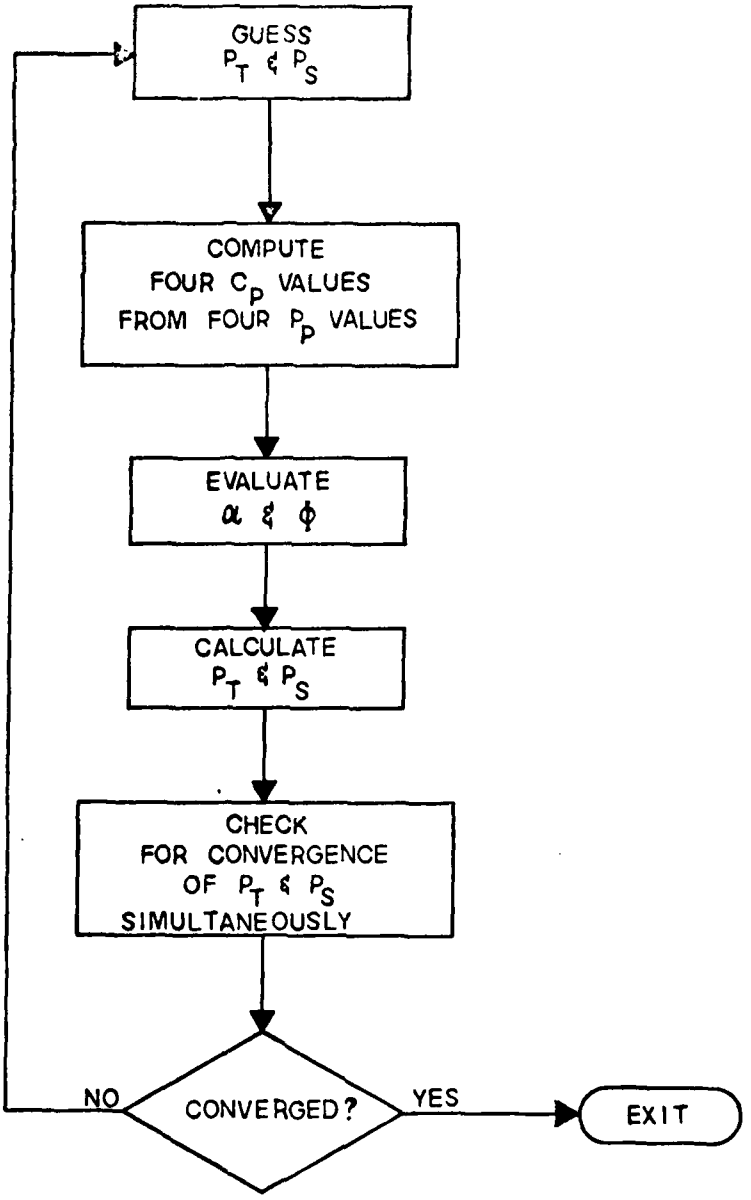

Fig. 2: Unstable iterative solution using measurement of A type and B type probes only.

fixed type B probe. The method of solution is then as shown in Fig. 3. The method shown in Fig. 3 proved to converge under all conditions. It is described in detail in the following pages.

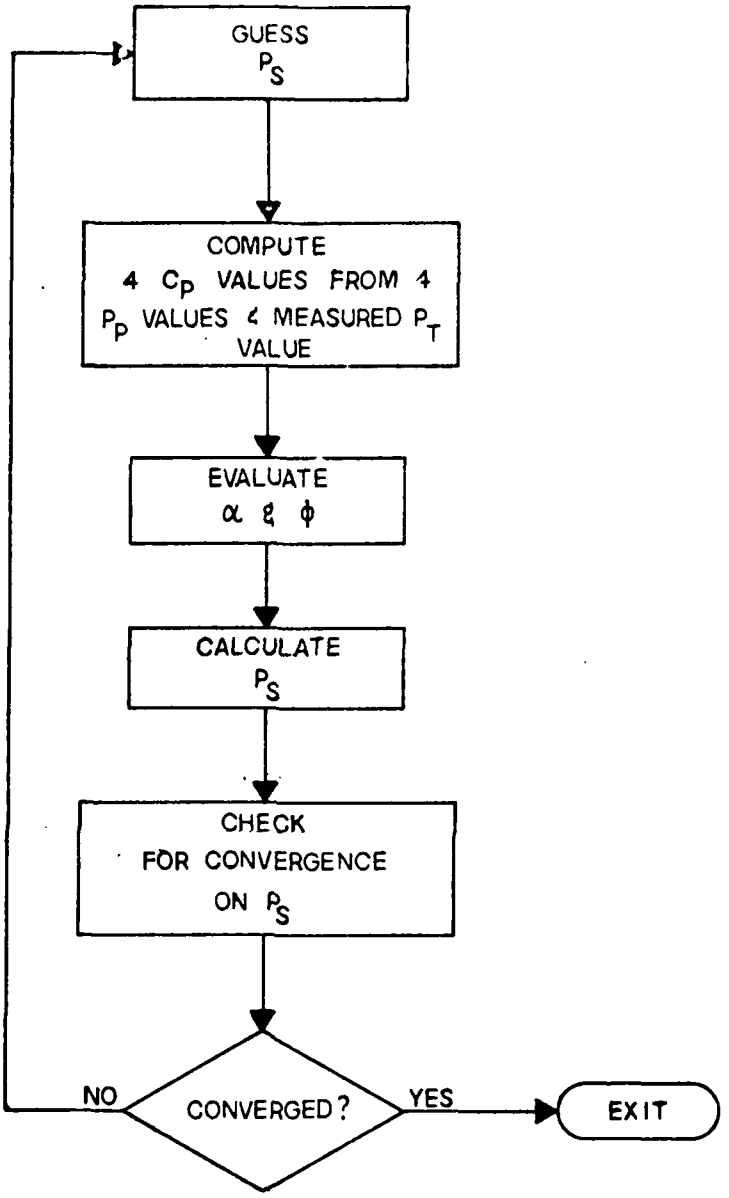

Fig. 3: Stable iterative solution using measurements of A type and B type probes as well as measurements of a Kiel probe.

Evaluation of α and ϕ (method)

The best way to understand the evaluation of yaw and pitch is to look at it from a topographical point of view. Each of the type A and type B probes has a unique calibration surface $Cp_{rp} = Cp_{rp}(\alpha_{rp}, \phi_{rp})$, where α_{rp} and ϕ_{rp} are measured relative to the axis of symmetry through the sensor at the probe tip. The calibration surface in this representation is invariant to yaw and pitch of the probe axis relative to the laboratory space. The same calibration surface if represented in the form $Cp = Cp(\alpha, \phi)$ can be written as

$$Cp = Cp[(\alpha_p + \alpha_{rp}), (\phi_p + \phi_{rp})] \tag{5}$$

where α_p and ϕ_p are the probe tip axis angular settings relative to the laboratory space. It is clear from eq. (5) that Cp can be derived from Cp_{rp} by a constant translation: α_p, ϕ_p on the α, ϕ plane. As each Cp_{rp} can be viewed as a hill with its peak at $\alpha_{rp} = 0$ and $\phi_{rp} = 0$. The Cp surfaces are the same hills with their peaks translated to $\alpha = \alpha_p$ and $\phi = \phi_p$.

In the present method probe A is used in three different angular settings namely:

I) $\alpha_p = 0$ $\phi_p = 0$

III) $\alpha_p = \alpha_{pIII} \quad \phi_p = 0$

IV) $\alpha_p = \alpha_{pIV} \quad \phi_p = 0$

and the B probe is used in a fixed position, namely:

II) $\alpha_p = 0 \quad \phi_p = \phi_{pII}$

For this case the topography of the calibration surfaces will appear as four hills. The three with their peaks at points (0,0); $(+\alpha_{pIII}, 0)$ and $(-\alpha_{pIV}, 0)$ are the translated hills Cp_{rpA} and the fourth with its peak at $(0, \phi_{pII})$ is the translated hill Cp_{rpB}. Their contours of constant Cp are then as shown in figure 4.

Assume now that a velocity vector with yaw α and pitch ϕ is to be measured. These values of α and ϕ will be sensed uniquely by the probes at their four angular settings. Were equation (4) single valued, the values of α and ϕ could be uniquely evaluated, as the single intersection point between the projections of appropriate lines of constant Cp on the α, ϕ plane*. In the present case of the double valued functions, the lines of constant Cp are closed curves and more than a single intersection point do exist.

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* Cp has generally a different value for each probe in each of its settings. Thus the solution involves solving for the intersection points between projections of contours of specified (but different) Cp values on the different hills.

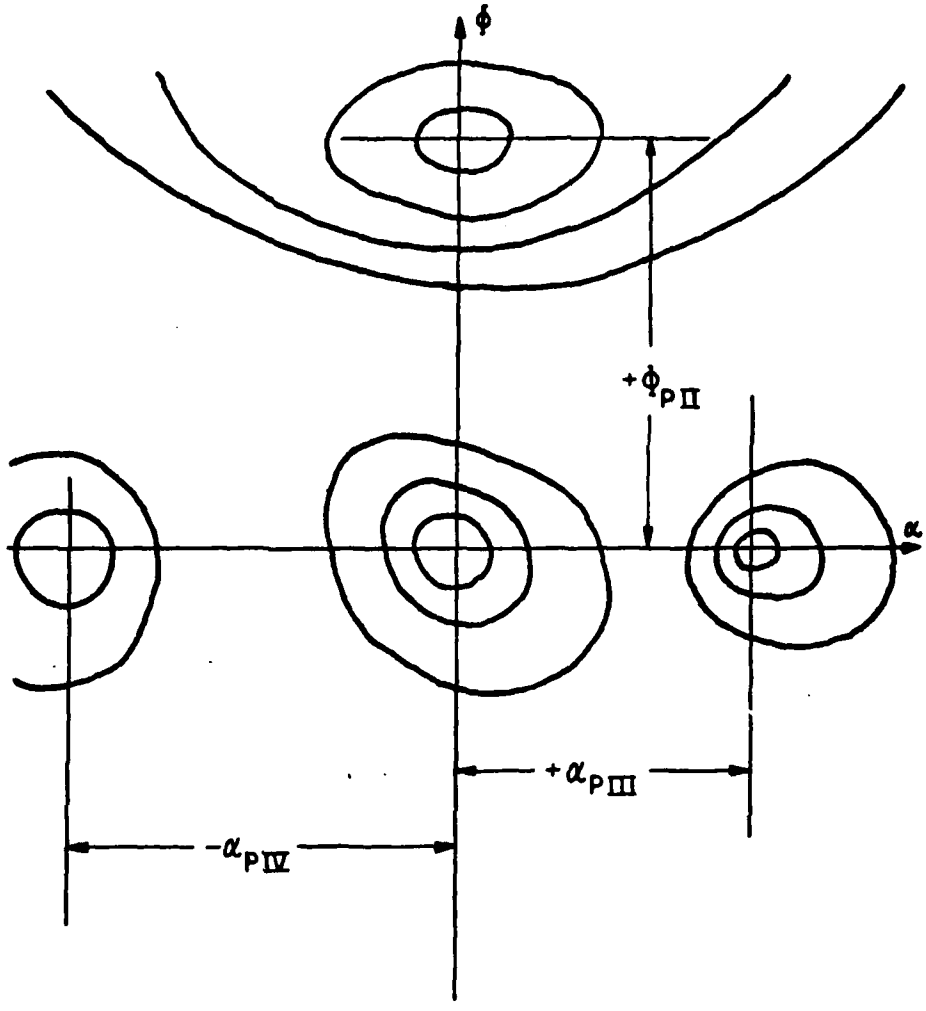


Fig. 4: Projections of C_p = const. lines of the four calibration surfaces (the center hill is for probe A at $\alpha_p = 0$, $\phi_p = 0$, the top hill is for probe B at $\alpha_p = 0$, $\phi_p = \phi_{pII}$, the right hill is for probe A at $\alpha_p = +\alpha_{pIII}$, $\phi_p = 0$ and the left hill is for probe A at $\alpha_p = \alpha_{pIV}$, $\phi_p = 0$.

The situation is shown in Fig. 5 for an example of a number of such intersection points. The correct intersection point, however, is uniquely identified as the only point through which all four Cp = const. curves pass.

From an examination of Fig. 5 it is clear that the intersection points of three closed Cp curves projections only are sufficient to identify α and ϕ uniquely. However one of these three curves must be that belonging to the type B probe.

The details of the numerical procedure used to obtain the correct intersection point in the evaluation of α and ϕ, are given in the following paragraph.

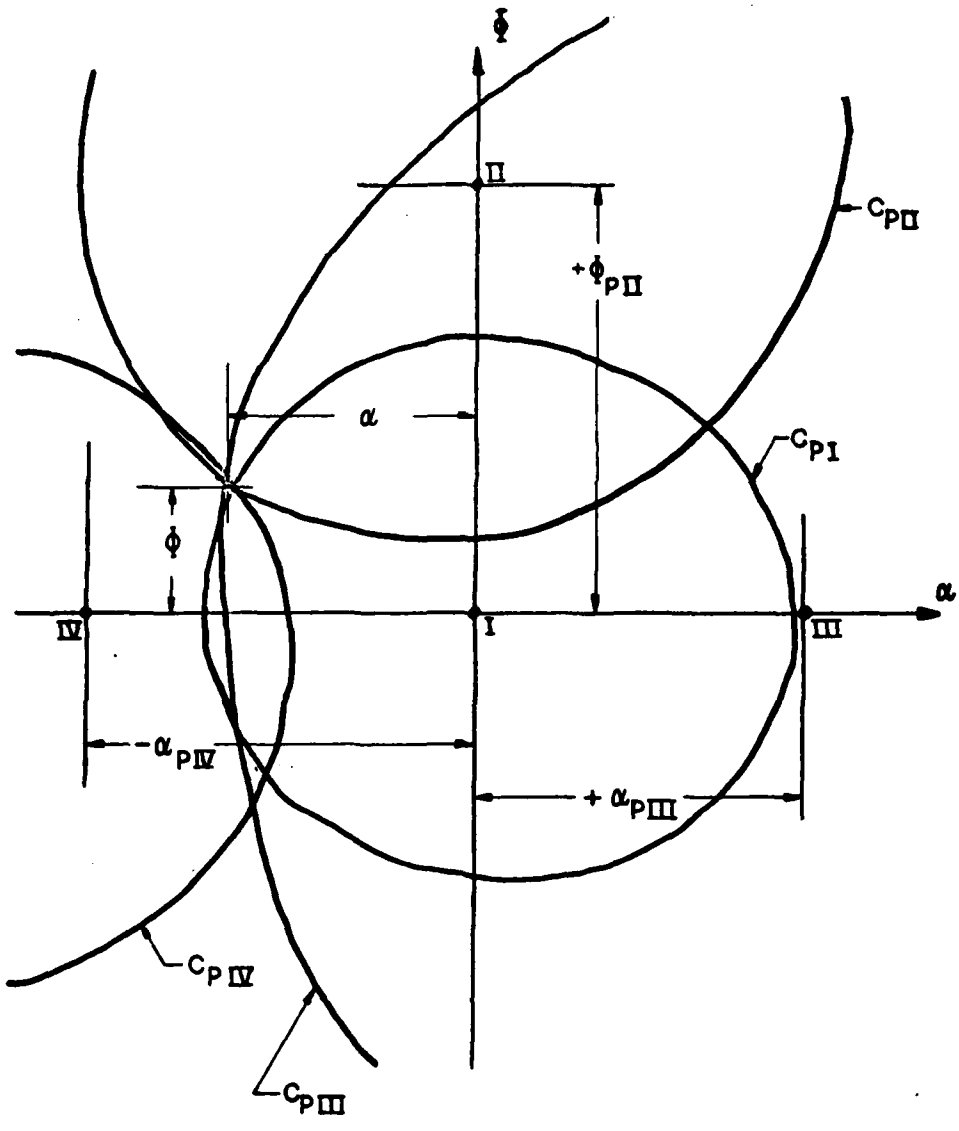


Fig. 5: An example showing a number of intersection points. The real one is in the second quadrant.

Evaluation of the intersection point coordinates (numerical Procedure)

The calibration surfaces Cp_{rp} are represented in form of a linear string of values ordered into an array, as shown schematically in figure 6. The numbers in Fig. 6 indicate the position of a Cp_{rp} value in the string. The string starts with the value of Cp_{rp} at a point $(-\alpha_{rpLo}; -\phi_{rpLo})$ and ends with the value of Cp_{rp} at a point $(+\alpha_{rpUp}; +\phi_{rpUp})$. This sequence must be kept and can not be changed.

Each of the closed Cp = const. curves projections in figs. 2 and 3 is the projection of the line of intersection between a plane parallel to the α,ϕ plane at a height equal to Cp and the calibration surface. These closed curves can be determined as the locus of the projections of all the penetration points of arbitrary lines parallel to the α,ϕ plane at a height Cp and the calibration surface. Such penetration points are calculated in subroutine "PENPTS", Fig. 10.

PENPTS calculates the first two penetration points of a surface Z (in the present case $Z = Cp$) by a straight line piercing that surface. If the surface is double valued these two points are the only roots. The surface is given as a table of numbers on a cartesian basis $Z = Z(X,Y)$ (or in the present case $Cp = Cp(\alpha,\phi)$.

The subroutine has the following limitations:

1) No roots can be found on the lower Y = const. boundary

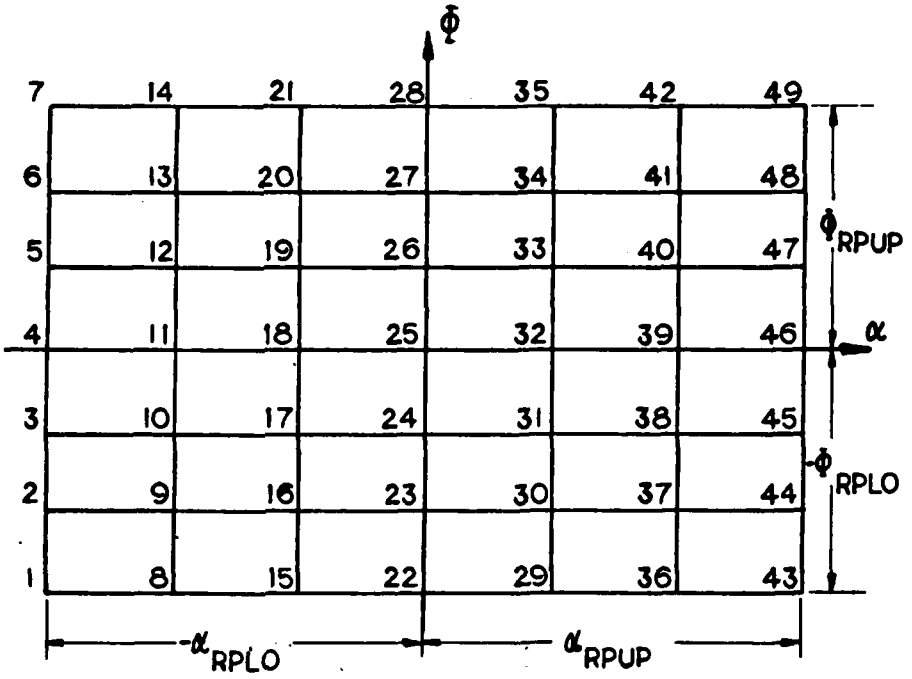


Fig. 6: The order of a calibration surface array.

2) The roots can be found only along a piercing line which is parallel to the X axis (but at any height above the X,Y plane)

3) The table Z = Z(X,Y) defining the surface must be based on a grid comprising lines X = const. and Y = const. The spacing of these lines must not be equal. In other words the surface is defined by a rectangular grid in the X,Y plane, from X_{min} to X_{max} and from Y_{min} to Y_{max}.

4) Only a single root can be evaluated in a surface element located above a defining rectangle on the X,Y plane.

5) Not more than the first two roots will be evaluated for any piercing line.

6) The surface must be monotonic over each rectangle (this is a result of limitation 4).

7) All X and Y arguments must be given in increasing order.

These limitations do not restrict the application of PENPTS in the present problem as long as the calibration surfaces are smooth within the element located above a grid rectangle. However, the elemental grid rectangles can be reduced arbitrarily in size. If a calibration surface is more than double valued PENPTS will fail. However in this case the probe yielding such a calibration surface can not be considered a useful instrument unless used only in parts of the domain where it is double valued.

Z is defined from X_{min} to X_{max} and from Y_{min} to Y_{max}. PENPTS is given the following initial information: X values and Y values defining grid points, corresponding Z values, the Y location (YG) and the height above the X,Y plane (HT) of the piercing line. With this information PENPTS searches for the band of rectangles which includes YG or of which YG is the lower boundary (see fig. 7) and then scans this band from left to right in search for penetration points. The scanning is based on the geometry given in fig. 7 which represents a particular element in the band, approximated by two plane triangles.

Initially a coarse scan is carried out just to detect, but not to evaluate, an intersection point. This is done checking for each sub-domain whether (ZX(I-1) - HT)/(ZX(I) - HT) 0. If this condition is true a root is detected and control is tranferred to its exact evaluation. The value of the root is calculated after its location, either in the first (left) or second (right) triangle is determined (each grid rectangle is composed of two triangles). Equation 6 which is based on fig. 8 (for a left triangle) or eq. 7 which is based on fig. 9 (for a right triangle) is used to evaluate the penetration point. These equations express the linear interpolation of Cp in the Fortran rotation used in this program.

```
XS = X(I-1) + ABS(ZX(I-1)-HT)*(XM-X(I-1))/(ABS(HT-ZM) +
   + ABS(ZX(I-1)-HT))                                          (6)
```

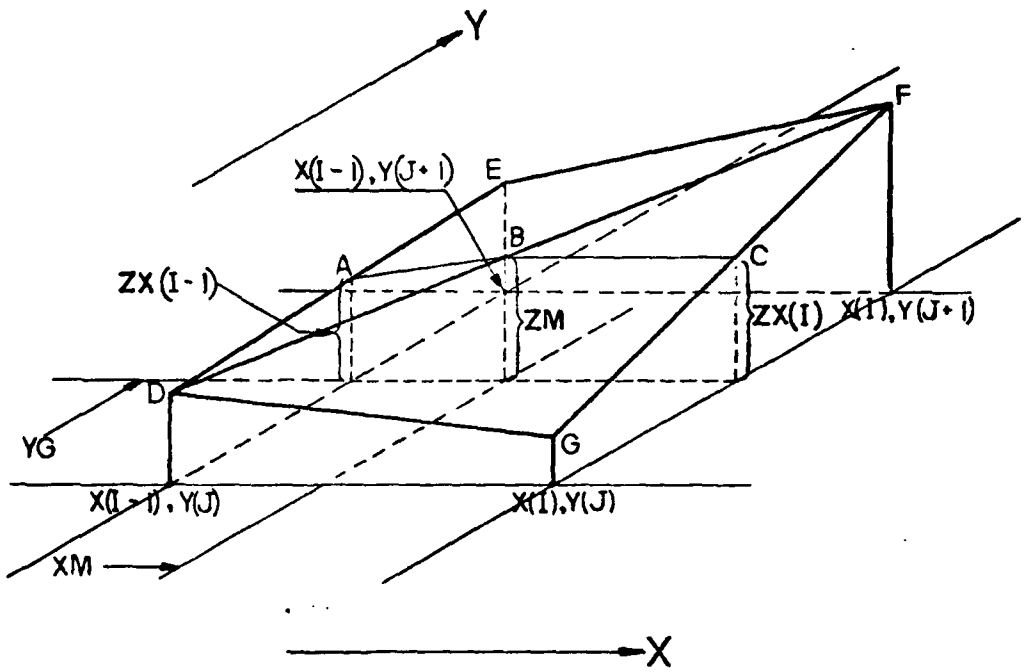


Fig. 7: The geometry of a linearized calibration surface element comprising two plane triangles and its intersection with a plane normal to X,Y along Y = YG.

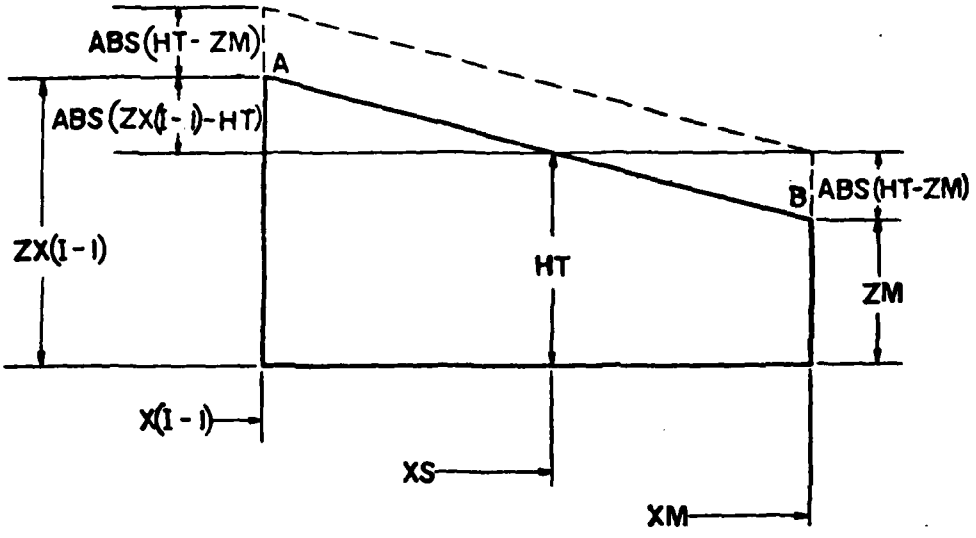


Fig. 8: The geometry for a penetration through a left hand (first) triangle.

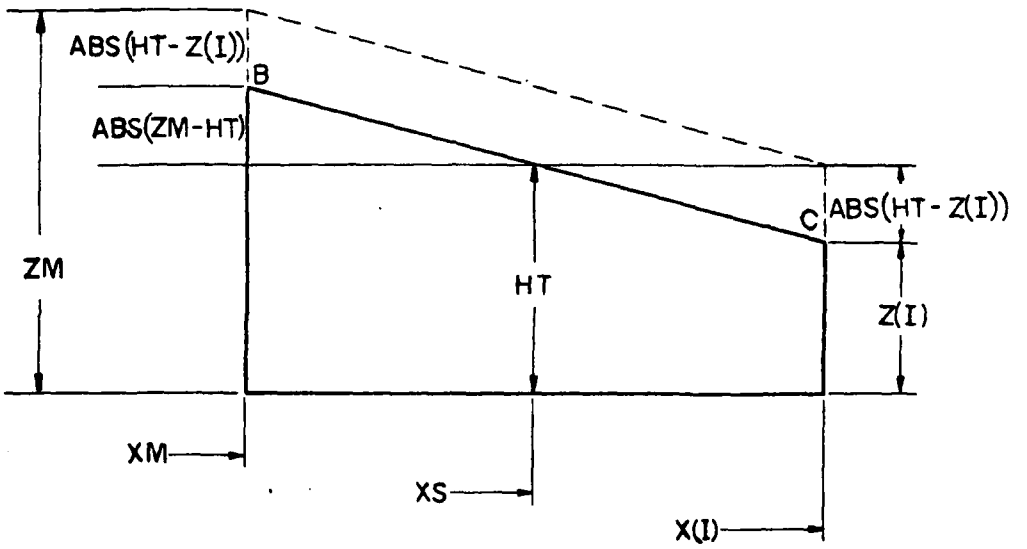


Fig. 9: The geometry for a penetration through a right hand (second) triangle.

```
XS = XM + (X(I)-XM)*ABS(ZM-HT)/(ABS(ZM-HT) +
     ABS(HT-Z(I)))                                    (7)
```

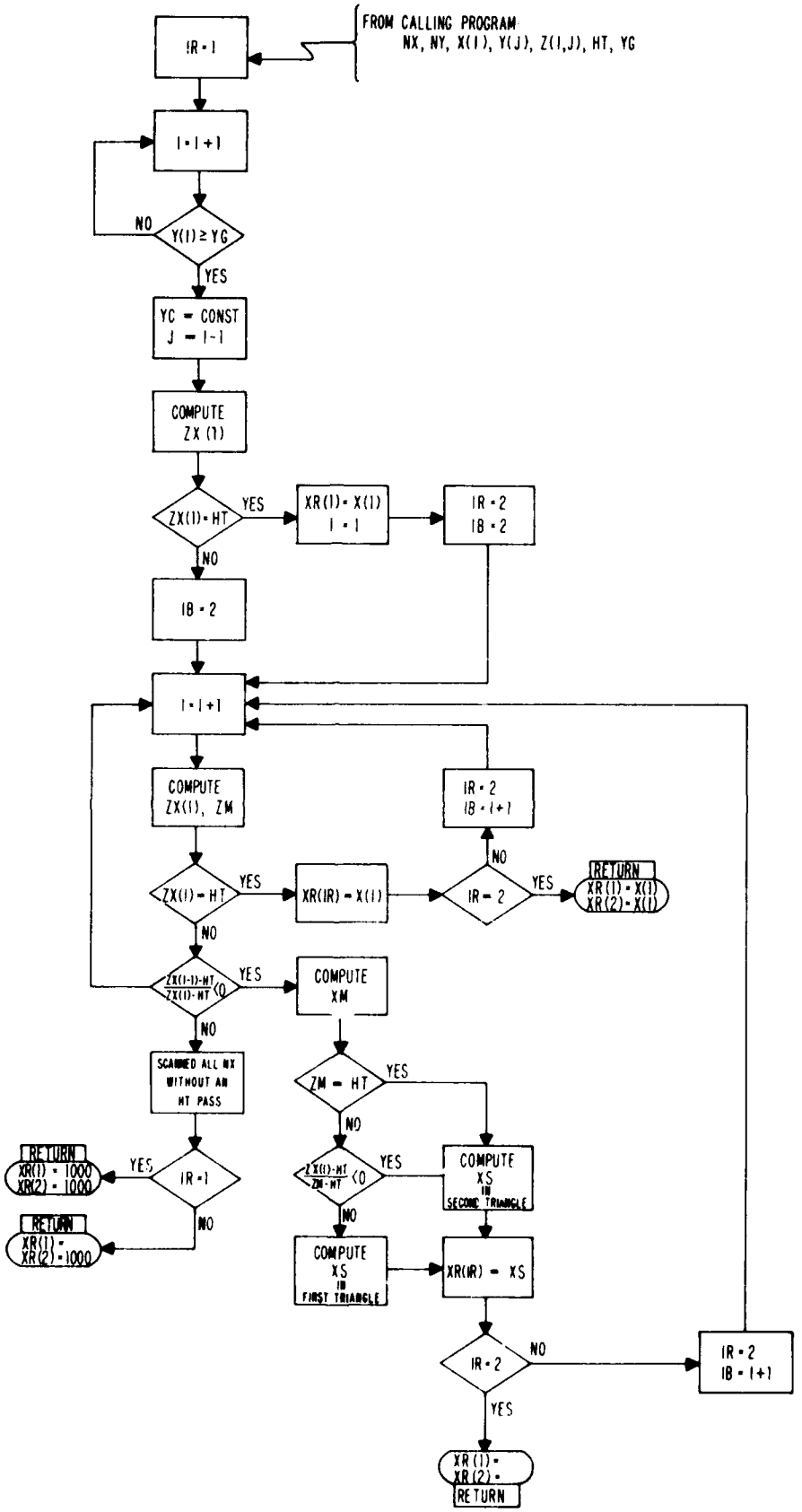
Equations 6 and 7 are invariant to the slope of the calibration surface i.e., the slope of the straight lines AB and BC.

Finally it should be pointed out that when two penetration points are determined the values of their abscissas, X(I), are returned. When only a single penetration point is detected the abscissa X(2) will be returned with a value of 1000.0. When no penetration point is determined both X(I) values returned will have the value of 1000.0. The program logic is designed to recognize these messages.

It was stated earlier that PENPTS is used to determine the closed intersection curves projections on the X,Y plane. In fact not the curves but just the intersection points between each two of them are required (see figure 3).

To compute the coordinates of these points the subroutine "INTSCS" is used. It uses PENPTS as a subroutine.

In INTSCS a scanning procedure is carried out from a minimal value of Y (or ϕ) YRIN to an upper value of YRUP, or a


FROM CALLING PROGRAM
NX, NY, X(I), Y(J), Z(I,J), HT, YG
IR = 1
I = I + 1
NO
Y(I) ≥ YG
YES
YC = CONST
J = I - 1
COMPUTE
ZX (1)
ZX(1) = HT
YES
XR(1) = X(1)
I = 1
IR = 2
IB = 2
NO
IB = 2
I = I + 1
COMPUTE
ZX(I), ZM
IR = 2
IB = I + 1
ZX(I) = HT
YES
XR(IR) = X(I)
NO
IR = 2
YES
RETURN
XR(1) = X(1)
XR(2) = X(I)
NO
(ZX(I-1)-HT)/(ZX(I)-HT) < 0
YES
COMPUTE
XM
NO
SCANNED ALL NX
WITHOUT AN
HT PASS
ZM = HT
YES
NO
(ZX(I)-HT)/(ZM-HT) < 0
YES
COMPUTE
XS
IN
SECOND TRIANGLE
NO
COMPUTE
XS
IN
FIRST TRIANGLE
XR(IR) = XS
IR = 1
YES
RETURN
XR(1) = 1000
XR(2) = 1000
NO
RETURN
XR(1) =
XR(2) = 1000
IR = 2
NO
IR = 2
IB = I + 1
YES
XR(1) =
XR(2) =
RETURN

prescribed 10,000 times* which ever comes earlier. The subroutine scans through any two arbitrarily chosen closed curve projections to find their intersection points. In each scan (I) up to four penetration points can be determined, while the penetration points of the previous scan (J) are memorized. Together, eight penetration points can be involved. When no intersection point exists the geometrical situation is as shown in figure 11, while the existance of an intersection point is characterized in figure 12. Subroutine INTSCS can distinguish between the two situations. In figures 11 and 12 the case of four penetration points found in each scan are shown. The subroutine, however will handle any possible number of such points, from zero to four. A "no penetration points" is assigned an abscissa value of 1000.0 by PENPTS as explained earlier.

When an intersection point is detected its evaluation is based on the geometry shown in fig. 12. The eight penetration points have the following coordinates:

AJL(RAJL,YRJ)	BJL(RBJL,YRJ)
BJR(RBJR,YRJ)	AJR(RAJR,YRJ)
BIL(RBIL,YR)	AIL(RAIL,YR)
AIR(RAIR,YR)	BIR(RBIR,YR)

---

* The 10,000 scans are governed by a program constant in the line "DO 140 ...." and can be arbitrarily varied.

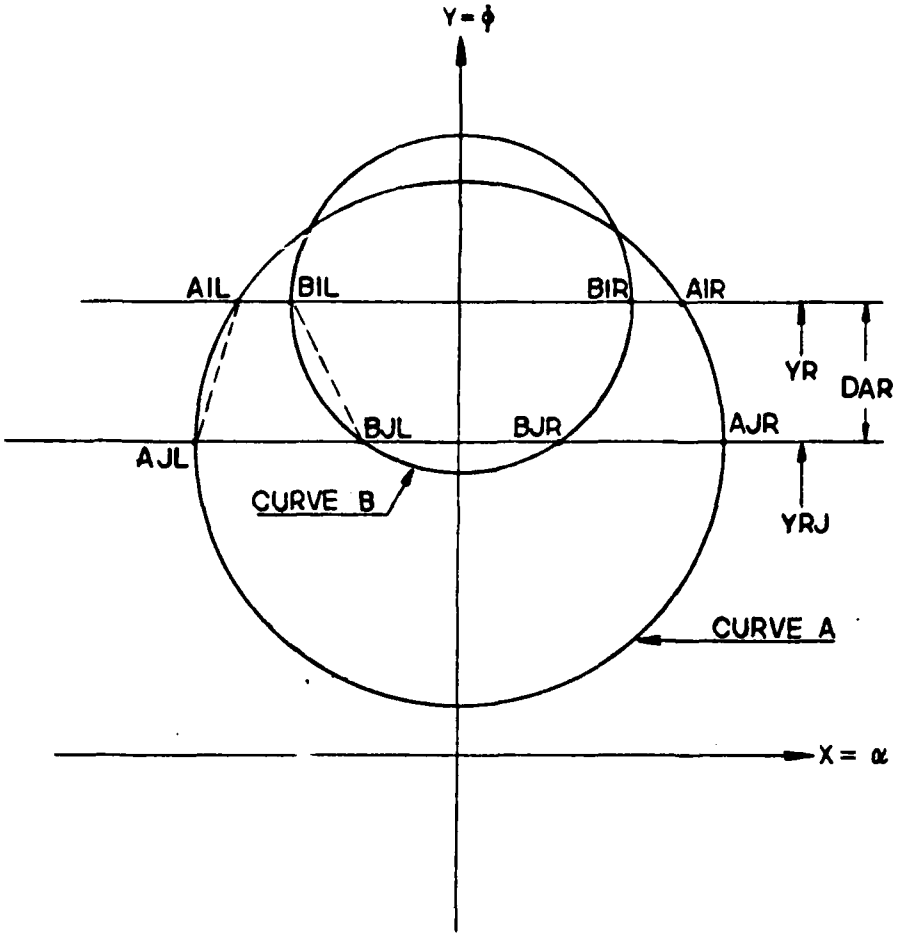


Fig. 11: The geometry for two successive scans when no intersection point exists.

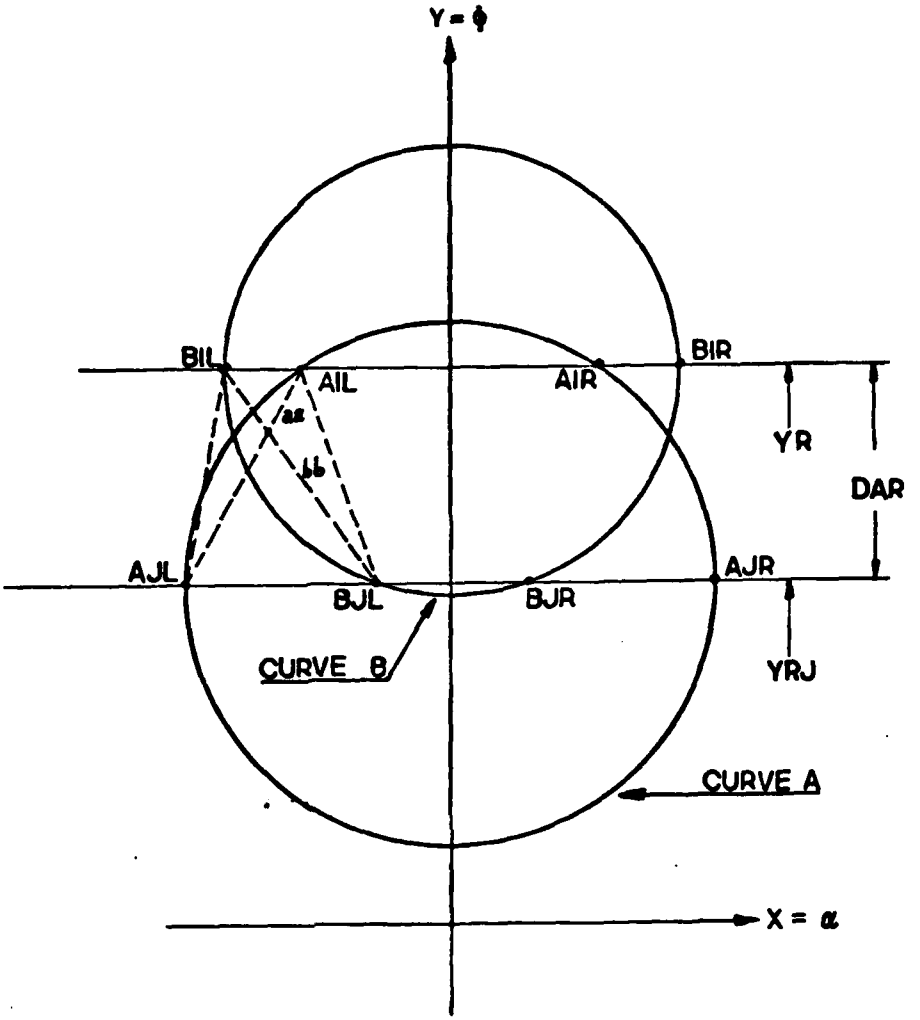


Fig. 12: The geometry for two successive scans when an intersection point does exist.

The left intersection point illustrated in fig. 12 is the intersection point of the lines aa and bb, each described by its equation:

for aa $Y = (AA)X + BA$ (8)

for bb $Y = (AB)X + BB$ (9)

The constants AA, BA, AB and BB are given in equations 10 to 13.

$AA = (YRJ-YR)/(RAJL - RAIL)$ (10)

$BA = YR - AA*RAIL$ (11)

$AB = (YRJ-YR)/(RBJL-RBIL)$ (12)

$BB = YR - AB*RBIL$ (13)

The coordinates of the intersection point to be calculated are

$X = (BB-BA)/(AA-AB)$ (14)

$Y = X*AA + BA$ (15)

These relations are true for a left hand intersection point. Analogous equations are true for a right hand intersection point. In this algorithm the straight lines aa and bb approximate the curved lines connecting AJL with AIL and BJL with BIL or similar lines on the right hand side of figure 12. The error introduced through this approximation is reduced as DAR = $\Delta\phi$ is reduced.

It is possible that an intersection point is identical with AIL and BIL or AIR and BIR. This case is defined as "direct hit". The program is designed to detect such a direct hit and evaluate the corresponding intersection point accordingly.

The above algorithm works perfectly as long as the two closed Cp = const. curves are far from being tangent. But in

practice a situation of almost tangent curves can arise when X (or α) is very small. In this case the preceeding algorithm will fail and must be replaced. The geometry of this situation is described in figure 13. This situation is identified by INTSCS and the intersection points are then evaluated assuming that they are intersections of two circular arcs. When the curves Cp = const. are almost circular this approximation does not lead to unacceptable errors.

It was stated earlier that INTSCS scans from a minimum value of ϕ to a maximum value of ϕ with prescribed steps $\Delta\phi$, as shown in figs. 11 and 12. This direction of the scanning is used when the intersection points of the curves Cp_I and Cp_{II} of fig. 5 are evaluated.

However, in course of the reduction of the measured data, scans in the direction of α in steps of $\Delta\alpha$ are also necessary to evaluate the intersections of the curves Cp_I and Cp_{III} or Cp_I and Cp_{IV}. INTSCS is designed to carry out this task as well. To do this the calling statement for INTSCS is appropriately changed as will be explained in the next section. To be general enough INTSCS is not written in terms of α and ϕ or X and Y but rather in terms of general arguments. The best way to understand INTSCS is to compare its general arguments to physical quantities by means of the calling statements. In fig. 14 the flow diagram in INTSCS is given in terms of the general arguments.

INTSCS returns to the main program (fig. 15) the (α,ϕ) coordinates of two intersection points between the Cp = const. curves specified in the calling statement. Let us now follow the way in which the main program is designed to utilize INTSCS

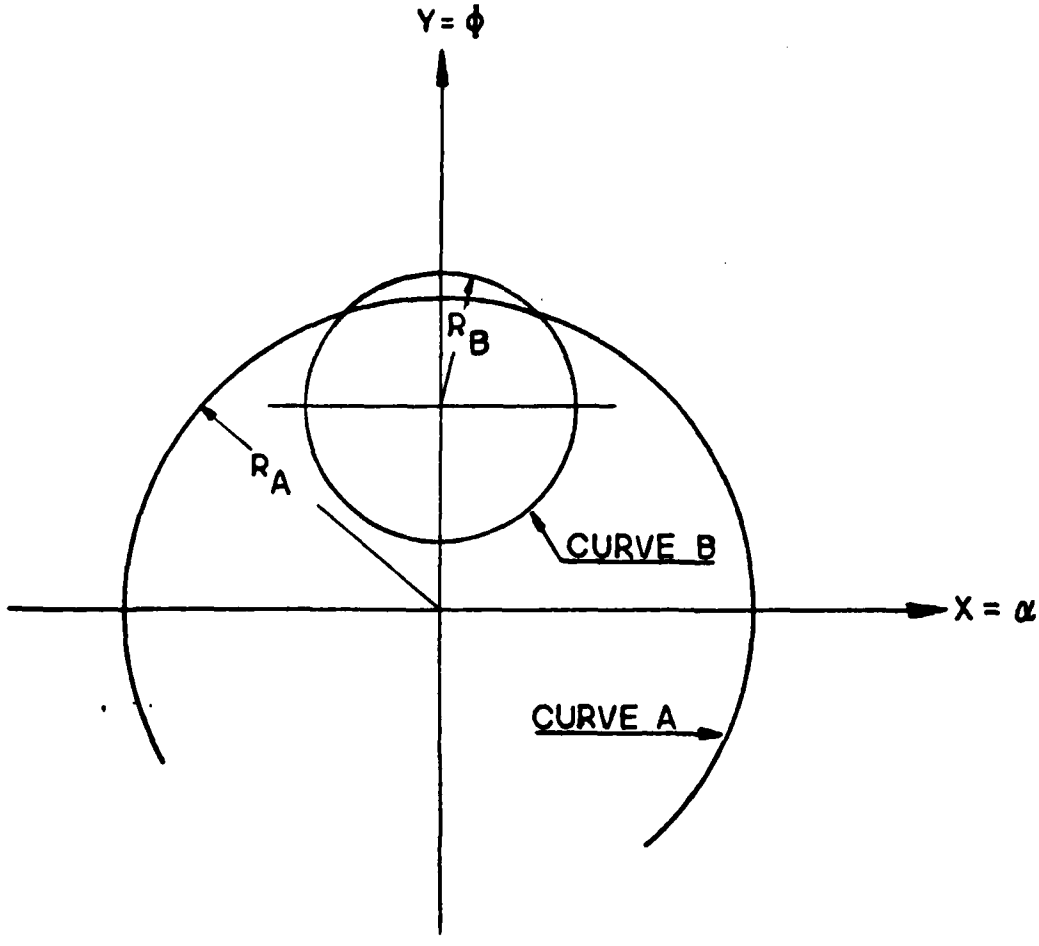


Fig. 13: The geometry when two closed C_p = const. curves are almost tangent.

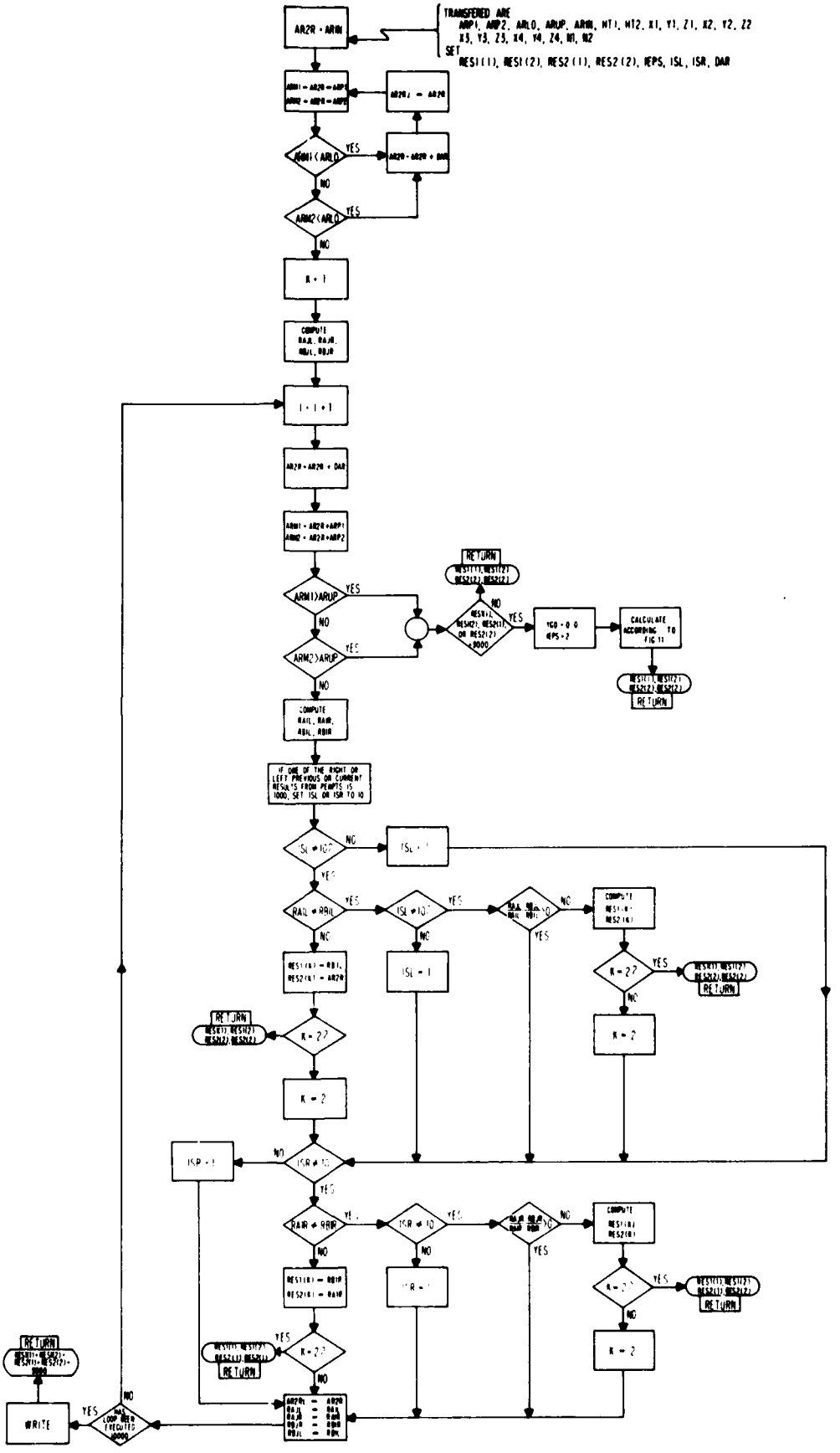


FIGURE 14. FLOW DIAGRAM OF INTSCS

for the evaluation of α and ϕ of the velocity vector, as well as static and total pressures.

Evaluation of the Velocity Vector and Pressures from the Probe Signals

Fortran program VDR was written to evaluate the velocity vector from probe measurements of pressures. The program is shown in Fig. 15.

At line 1410 INTSCS is called to scan curves I and II for possible intersection points. Scanning can be carried out in the direction of the ordinate only, with the calibration curve matrices compiled exactly as shown in fig. 6. This limitation is imposed by the way PENPTS is constructed. In the case of the intersection points between I and II ZA and ZB are scanned without difficulties in the direction of the ordinate which is ϕ as shown in fig. 12 and returns with the coordinates of the two first intersection points, points 1 and 2 of Fig. 16. They are ALF1, PHI1 and ALF2, PHI2. In line 1500 INTSCS is called again to scan curves I and III. Now scanning has to be carried out in the direction of the abscissa, a task for which INTSCS was not designed. To overcome this problem the calibration curve matrices are used in a transformed form such that the previous abscissas are now ordinates, ordinates are abscissas and the internal structures of the Cp_{rp} arrays are accordingly modified. This transformation is carried in VDR in the section between lines 320 and 450. Comparison of the calling line 1500 to the previous calling line 1410 shows very clearly how the various arrays: original and transformed, are used. The coordinates of points 3 and 4 of fig. 16

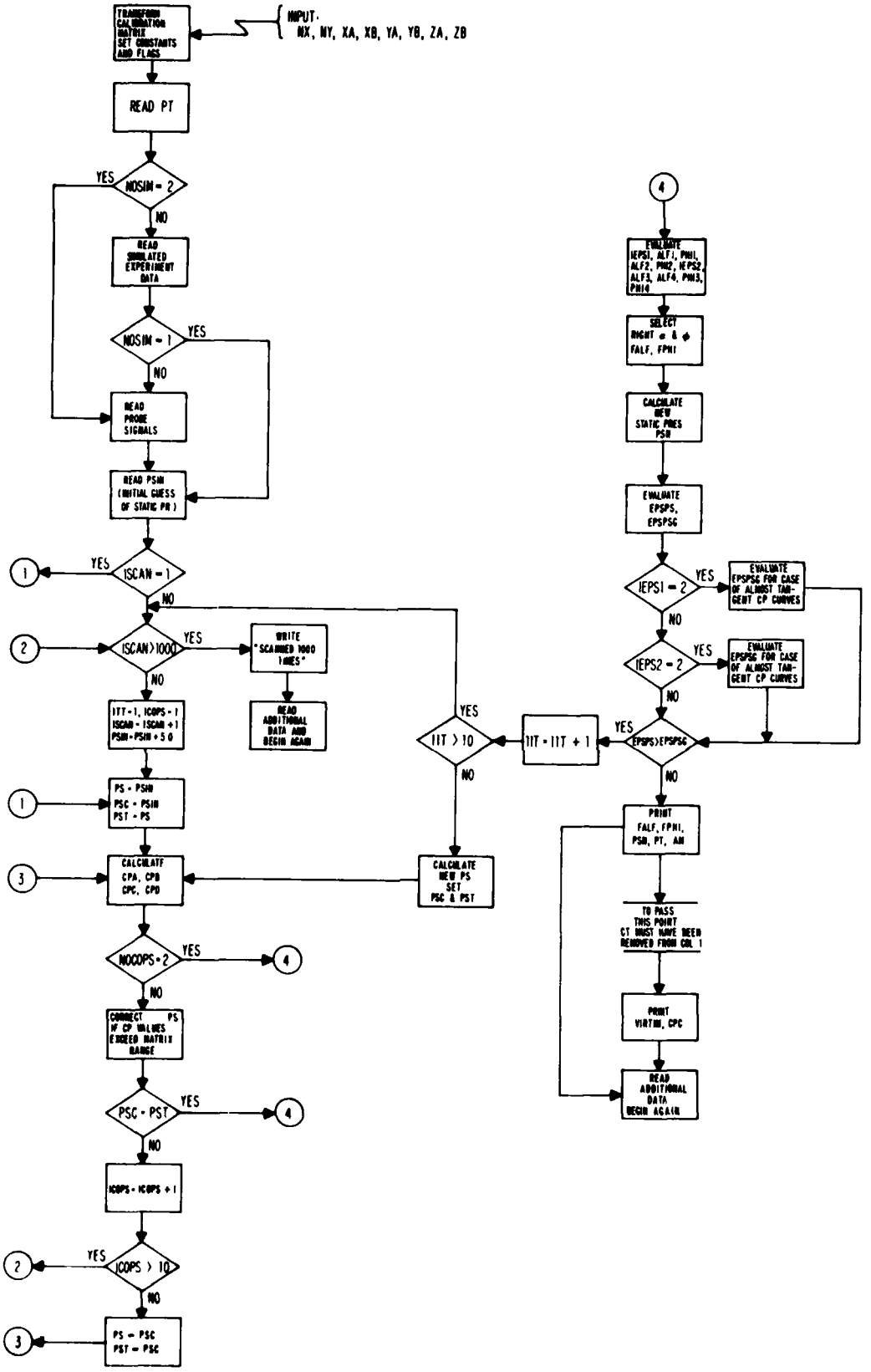


FIGURE 15. FLOW DIAGRAM OF VDR

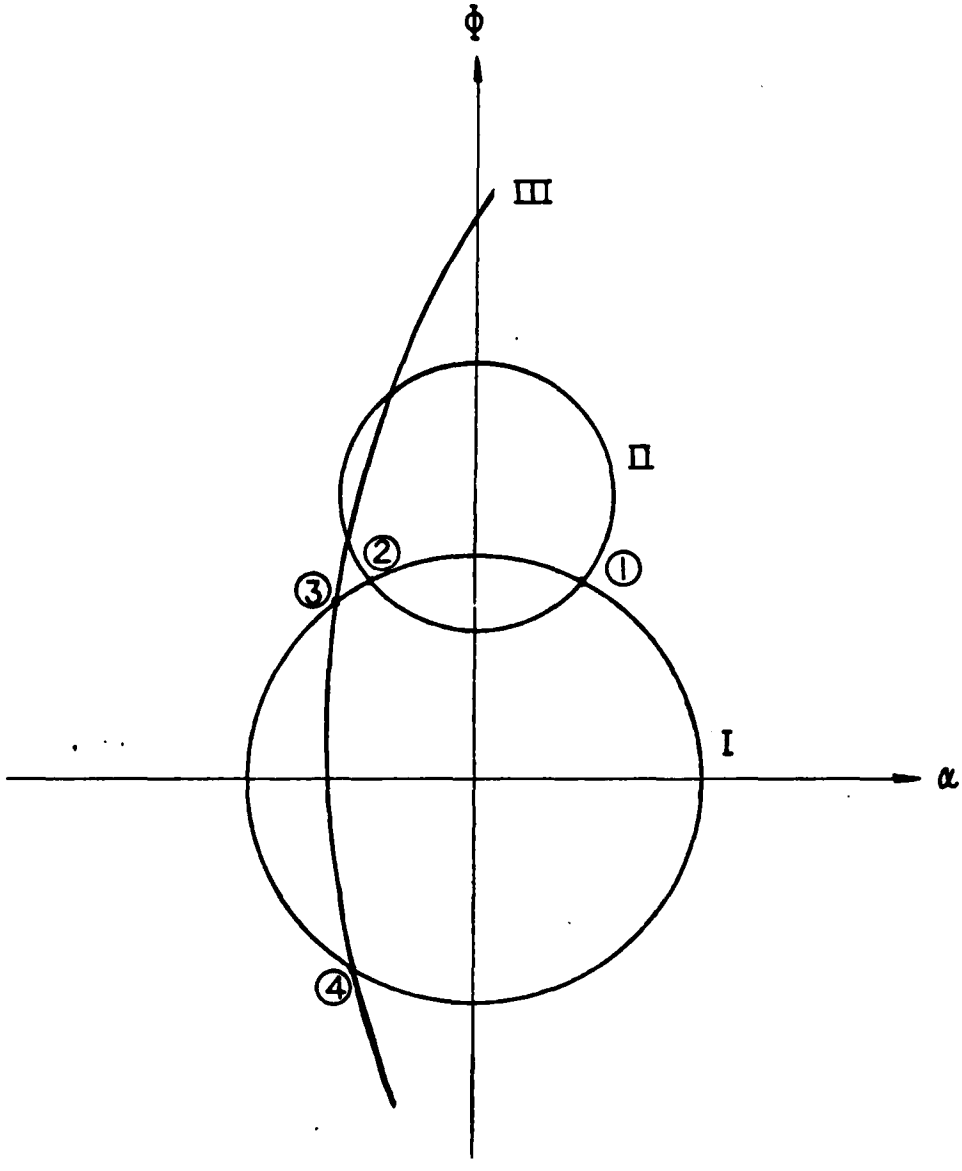


Fig. 16: Selection of the proper intersection point in VDR.

are now returned to the main program of VDR, they are ALF3,PHI3 and ALF4,PHI4.

We are seeking a single intersection point; the one representing yaw and pitch as sensed by probe A in positions I and III and probe B in position II. But, as the calibration surfaces are double valued we are now, unfortunately, in the possession of four points. The solution, however, is physically unique. Only a single velocity vector exists in reality and its yaw and pitch are included in the four intersection points evaluated. Were both the measurements and the numerical procedure absolutely accurate, two of the four points would have been identical. But this is not the case in reality, instead of a single point, two points close to each other will be detected. Therefore the average coordinates of the two of the four intersection points returned to VDR from INTSCS which are closest to each other are selected as the measured yaw and pitch angles. In the example shown in fig. 16 this will be the point dividing the distance between points 2 and 3.

The calculation is now at the point at which α and ϕ are temporarily known (see fig. 3). Using α and ϕ a new Cp_{rpIV} (for probe A in position IV) is computed by linear interpolation using subroutine INTPLT. With this new value of Cp_{rpIV} and with Pp_{IV} a new P_s is computed. If this new value of P_s is close enough as determined by EPSPSG to the guessed value, or to the value of P_s in the previous iteration, the data reduction for the particular point in question is terminated.

The relative difference between present and previous P_s is compared to the convergence criterion EPSPSG. This criterion is evaluated by an empirical function determined to give best compromise between accuracy of results and computer time required until convergence is achieved. When the calculation follows normal routine the convergence criterion is given in line 1710 as function of P_T . When the routine for almost tangent curves is used during data reduction either on the right or the left side a different empirical function (lines 1720 or 1730) is used.

If the convergence criterion is satisfied results are printed out and data for a new measurement point is read for reduction. If, however convergence is not reached a new static pressure for a next iteration is evaluated (line 1780).

Convergence and accuracy

The convergence of the present iterative procedure is not ensured in all possible cases of data sets. The program, however, is adjusted to converge in most of the cases. Similarly to other iterative computation method some experience is required to achieve convergence when the calculation does not converge. In this paragraph the principal factors affecting convergence, computation time and accuracy, which are abviously coupled, are pointed out.

The convergence and accuracy of reduction of a data set: P_T, PPA, PPB, PPC, PPD, PSIN (or analogous set in the experiment simulation mode) depends on the following factors, which can be varied by the user.

1) Coarseness of calibration arrays ZA, ZB and their linearity. With coarser arrays convergence problem will increase and accuracy of results decrease.

2) Probe settings YPB, XPC, XPD (with the following probe settings being fixed and not variable YPA = YPC = YPD = 0.0; XPA = XPB = 0.0). The optimum setting is about $\pm 20^{o}$ to 25^{o}. Too small values reduce accuracy, too big values cause convergence problems and probe tip flow separation.

3) RELXPS, the static pressure relaxation factor. The smaller this factor the safer will convergence be achieved. Computation time, however, will increase.

4) The constant 5.0 in line 1050 of the program. The dimension of this constant is kg/m^2. If too big results can be lost and if too small computer time will be growing. The variation of this constant should be coupled with an appropriate modification of the constant in line 1010 of VDR (item 8 in this list).

5) The constants in the evaluation of EPSPSG (lines 1710 to 1730). The smaller EPSPSG the more accuarte the results in expense of increased computation time and reduced convergence safety.

6) The constant scanning step DAR. The smaller DAR the more accurate the results, but too small values can cause complete loss of results. Computation time increases with reduced DAR.

7) The constant 10 in line 1360. This constant governs the number of P_s corrections.

8) The constant 1000 in line 1010. This constant governs the number of scans.

If convergence is not achieved in a particular case variation of each or of a combination of the above values will always enable convergence.

Evaluation of the Computation Time

By deleting the letters CT from column 1 and 2 of lines 20 to 70, 1930 to 1960, 1980, 2000, 2010 the actual computation time as well as CPU time are evaluated and printed out. The following statement prior to execution is required in this case:*

GLOBAL T SYSLIB SSPLIB

This option is useful for adjusting the constants affecting convergence as to optimal compromise between accuracy, ease of convergence and calculation costs.

---

* When the program is run on Naval Postgraduate School IBM 360 system.

Input

1) Calibration arrays have to be input in the following manner: first values of NX and NNY , second values of X in rising order, third values of Y in rising order and fourth values of Z in the order shown in Fig. 6. Two calibration arrays are read: first the array of type A probe and second the array of type B probe.

2) If the program is run in experiment simulation mode PT and PS are read in Kg/m^2 and subsequently α and ϕ .

3) If the program is run in data reduction mode the measured values of PT, PPA, PPB, PPC and PPD are read and then the guess of static pressure PSIN. All are read in Kg/m^2. PSIN has to be lower than the actually existing value to ensure convergence of the calculation. Too low a value will cause waste of computer time.

Calibration arrays are read from a disk space on which they are stored. The following statement prior to execution is required for successful reading:

FILEDEF 02 DSK NAME XX

here NAME is the name of the file on which the calibration data of probes A and B is stored in proper order and format, XX is a two digit number.

Simulation or measurements reduction input is read in the normal way using the terminal keyboard or punched cards.

Output

α, ϕ, P_S, P_T and Ma are printed out according to lines 1820 to 1920. This output, however is not sufficient when the logic of the computation is to be followed either to examine the execution of the program or for debugging. Two programs with additional output are given in appendices 2 and 3 and can be used for this purpose. The first, SWVDR gives short additional output, namely:

1) When PSIN is successively increased automatically by the program to ensure convergence, the values of PSIN are printed out.

2) IIT, FALF, FPHI and PSN are printed out at the end of each iteration prior to the convergence test.

The second program WVDR prints more detailed information. All additional WRITE statements in this program are numbered with three digit numbers starting with 9.

Conclusions

The following conclusions are drawn on the basis of experience gained in running the program with various data sets and various types of calibration surfaces.

1) Optimal probe settings for ease of convergence and high accuracy are: YPB = 25°, XPC = 25°, XPD = -25°. It is therefore suggested that a B type probe with 25° pitch will be used, and that the A type probe be rotated to $\pm$ 25°.

2) Convergence and accuracy, as well as computer time efficiency are improved when the calibration surfaces of both probes are not flat at their peaks but are rather rounded. It is therefore suggested that a new probe tip geometry be considered. A spherical tip with a central pressure tap is recommended. To prevent damage to the sensitive transducer located behind the pressure tap, and in order to improve the frequency response of the probes it is suggested that the volume between the pressure tap face and the transducer be filled with an appropriate liquid that will not affect the transducer negatively. In this case the opening of the pressure tap has to be sealed with a very thin low inertia membrane.

3) It is probably possible to modify the iterative procedure such that safe convergence can be achieved also when using the scheme of Fig. 2. If this can be achieved the Kiel probe will not be necessary. An effort in this direction is suggested.

References

1. Dunker R. J., Strinning P. E., and Weyer, H. B., "Experimental Study of the Flow Field Within a Transonic Axial Compressor Rotor by Laser Velocimetry and Comparison With Through-Flow Calculations", ASME Journal of Engineering for Power, Vol. 100, pp. 279-286, April 1978.
2. Shreeve, P. P., Simmons J. M., Winters K. A., and West J. C. Jr., "Determination of Transonic Compressor Flow Field by Synchronized Sampling of Stationary Fast Response Transducers", Symposium on Non-Steady Fluid Dynamics, ASME 1978 Winter Annual Meeting, San Francisco, Dec 1978. (To be published in ASME Journal of Fluids Engineering)
3. Thompkins W. T. Jr., and Kerrebrock J. L., "Exit Flow From a Transonic Compressor Rotor", AGARD Conference Proceedings No. 177, Unsteady Phenomena in Turbomachinery, pp. 6-1 to 6-23. Meeting held at Naval Postgraduate School, Monterey, California, 22-26 September 1975.
4. Shreeve R. P., McGuire A. G., and Hammer J. A., "Calibration of a Two Probe Synhronized Sampling Technique for Measuring Flows Behind Rotors", paper to be presented at IEEE, Eighth International Congress in Instrumentation in Aerospace Simulation Facilities, Naval Postgraduate School, Monterey, September 24-26 1979. Published as IEEE ICIASF Record of Proceedings.

APPENDIX I

LISTING OF VDR

07/08/79 18.43.34

FILE: VDR FORTRAN P1 N P S

```
C START OF VDR                                                          INT00010
CT      INTEGER A(6)                                                    INT00020
CT      IASC=0                                                          INT00030
CT      IAC=1                                                           INT00040
        DIMENSION ALF(40),PHI(40),XA(40),YA(40),                        INT00050
       1ZA(40,40),XB(40),YB(40),ZB(40,40),XAX(40),YAX(40),              INT00060
       2ZAX(40,40),XBX(40),YBX(40),ZBX(40,40)                           INT00070
119     FORMAT(2I5)                                                     INT00080
131     FORMAT(F7.1)                                                    INT00090
130     FORMAT(F5.1)                                                    INT00100
120     FORMAT(F8.2)                                                    INT00110
132     FORMAT(F10.2)                                                   INT00120
135     FORMAT(F15.5)                                                   INT00130
136     FORMAT(F17.5)                                                   INT00140
C READ PROBE CALIBRATION DATA                                           INT00150
        READ(2,119) NX,NY                                               INT00160
        DO 121 I=1,NX                                                   INT00170
121     READ(2,130) XA(I)                                               INT00180
        DO 122 I=1,NY                                                   INT00190
122     READ(2,130) YA(I)                                               INT00200
        DO 123 I=1,NX                                                   INT00210
        DO 123 J=1,NY                                                   INT00220
123     READ(2,120) ZA(I,J)                                             INT00230
        DO 221 I=1,NX                                                   INT00240
221     READ(2,130) XB(I)                                               INT00250
        DO 222 I=1,NY                                                   INT00260
222     READ(2,130) YB(I)                                               INT00270
        DO 223 I=1,NX                                                   INT00280
        DO 223 J=1,NY                                                   INT00290
223     READ(2,120) ZB(I,J)                                             INT00300
C TRANSFORM CALIBRATION MATRICES                                        INT00310
        DO 224 I=1,NY                                                   INT00320
224     XAX(I)=XA(I)                                                    INT00330
        DO 225 I=1,NX                                                   INT00340
225     YAX(I)=XA(I)                                                    INT00350
        DO 226 I=1,NY                                                   INT00360
        DO 226 J=1,NX                                                   INT00370
226     ZAX(I,J)=ZA(J,I)                                                INT00380
        DO 227 I=1,NY                                                   INT00390
227     XBX(I)=YB(I)                                                    INT00400
        DO 228 I=1,NX                                                   INT00410
228     YBX(I)=XB(I)                                                    INT00420
        DO 229 I=1,NY                                                   INT00430
        DO 229 J=1,NX                                                   INT00440
229     ZBX(I,J)=ZB(J,I)                                                INT00450
C PROBE SETTINGS                                                        INT00460
        YPA=0.0                                                         INT00470
        YPE=55.                                                         INT00480
        XPA=0.0                                                         INT00490
        XPC=20.                                                         INT00500
        XPL=-20.                                                        INT00510
C PROGRAM CONSTANTS                                                     INT00520
        YRLO=-30.                                                       INT00530
        YRUP=30.                                                        INT00540
        YRIN=-30.                                                       INT00550
        XRLO=-30.                                                       INT00560
        XRUP=30.                                                        INT00570
        XRIN=-30.                                                       INT00580
        ICOPS=1                                                         INT00590
        NOCOPS=1                                                        INT00600
        NOSIM=1                                                         INT00610
        ILT=1                                                           INT00620
        ISCAN=1                                                         INT00630
        RELXPS=0.5                                                      INT00640
C EXPERIMENT SIMULATION                                                 INT00650
401     FORMAT(F15.4)                                                   INT00660
193     READ(5,401) PT                                                  INT00670
        WRITE(6,401) PT                                                 INT00680
        IF(NOSIM.EQ.1) GO TO 500                                        INT00690
        READ(5,401) PS                                                  INT00700
```

```
FILE: VOR      FORTRAN  P1                    N     P              S

      WRITE(6,401) PS                                                  INTJ0710
      READ(5,401) ALFA                                                 INTJ0720
      WRITE(6,401) ALFA                                                INTC0730
      READ(5,401) PHII                                                 INTJ0740
      WRITE(6,401) PHII                                                INTJ0750
      CALL INTPLT(XA,YA,ZA,ALFA,PHII,NX,NY,CPA)                        INTJ0760
      ALFC=ALFA-APC                                                    INTJ0770
      CALL INTPLT(XA,YA,ZA,ALFC,PHII,NX,NY,CPC)                        INTC0780
      ALFD=ALFA-APD                                                    INTC0790
      CALL INTPLT(XA,YA,ZA,ALFD,PHII,NX,NY,CPD)                        INTJ0800
      PHIB=PHII-YPB                                                    INTC0810
      CALL INTPLT(XB,YB,ZB,ALFA,PHIB,NX,NY,CPB)                        INTJ0820
      PDYN=PT-PS                                                       INTJ0830
      PPA=CPA*PDYN+PS                                                  INTC0840
      PPB=CPB*PDYN+PS                                                  INTJ0850
      PPC=CPC*PDYN+PS                                                  INTC0860
      PPD=CPD*PDYN+PS                                                  INTJ0870
C READ MEASUREMENTS DATA                                               INTC0880
      IF(NCS4.EQ.1) GO TO 501                                          INTC0890
50C   READ(5,135) PPA                                                  INTJ0900
      WRITE(6,136) PPA                                                 INTJ0910
      READ(5,135) PPB                                                  INTJ0920
      WRITE(6,136) PPB                                                 INTJ0930
      READ(5,135) PPC                                                  INTC0940
      WRITE(6,136) PPC                                                 INTC0950
      READ(5,135) PPD                                                  INTJ0960
      WRITE(6,136) PPD                                                 INTC0970
501   READ(5,135) PSIN                                                 INTJ0980
      WRITE(6,136) PSIN                                                INTJ0990
      IF(ISCAN.EQ.1) GO TO 181                                         INTC1000
180   IF(ISCAN.GT.1000) GO TO 305                                      INTJ1010
      IIT=1                                                            INTJ1020
      ICOPS=1                                                          INTJ1030
      ISCAN=ISCAN+1                                                    INTJ1040
      PSIN=PSIN+5.0                                                    INTC1050

181   PS=PSIN                                                          INTJ1070
      PSC=PSIN                                                         INTC1080
      PST=PS                                                           INTJ1090
C CALCULATES PRESSURE COEFFICIENTS                                     INTJ1100
30C   PDYN=PT-PS                                                       INTC1110
      CPA=(PPA-PS)/PDYN                                                INTJ1120
      CPB=(PPB-PS)/PDYN                                                INTC1130
      CPC=(PPC-PS)/PDYN                                                INTJ1140
      CPD=(PPD-PS)/PDYN                                                INTJ1150
C CORRECTS PS ASSUMPTION TO ENSURE CP ARE IN CALIBRATION RANGE         INTC1160
      IF(NOCPS.EQ.2) GO TO 301                                         INTJ1170
      ZAMAX=-10000.                                                    INTJ1180
      CALL MAXARY(ZA,ZAMAX,NX,NY)                                      INTJ1190
      IF(CPA.GT.ZAMAX) PSC=1.01*PS                                     INTJ1200
      IF(CPC.GT.ZAMAX) PSC=1.01*PS                                     INTC1210
      IF(CPD.GT.ZAMAX) PSC=1.01*PS                                     INTC1220
      ZBMAX=-10000.                                                    INTJ1230
      CALL MAXARY(ZB,ZBMAX,NX,NY)                                      INTC1240
      IF(CPB.GT.ZBMAX) PSC=1.01*PS                                     INTJ1250
      ZAMIN=10000.                                                     INTJ1260
      CALL MINARY(ZA,ZAMIN,NX,NY)                                      INTC1270
      IF(CPA.LT.ZAMIN) PSC=0.99*PS                                     INTJ1280
      IF(CPC.LT.ZAMIN) PSC=0.99*PS                                     INTC1290
      IF(CPD.LT.ZAMIN) PSC=0.99*PS                                     INTJ1300
      ZBMIN=10000.                                                     INTC1310
      CALL MINARY(ZB,ZBMIN,NX,NY)                                      INTC1320
      IF(CPB.LT.ZBMIN) PSC=0.99*PS                                     INTJ1330
      IF(PSC.EQ.PST) GO TO 301                                         INTC1340
      ICOPS=ICOPS+1                                                    INTJ1350
      IF(ICOPS.GT.10) GO TO 180                                        INTJ1360
      PS=PSC                                                           INTC1370
      PST=PSC                                                          INTC1380
      GO TO 300                                                        INTJ1390
C CALCULATES TRU ALF & PHI ANGLES FOR 'I' & 'II'                       INTJ1400
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FILE: VOR       FORTRAN  P1                          N     P              S

301   CALL INTSCS(XPA,YPS,YRLC,YPUP,YRIN,                                    INTC1410
     1CPA,CPE,ALF,PHI,XA,YA,ZA,                                             INTC1420
     2XB,YB,ZB,AX,YAX,ZAX,XEX,YEX,ZEX,NX,NY,IEPS)                           INTC1430
      IEPS1=IEPS                                                            INTC1440
      ALF1=ALF(1)                                                           INTC1450
      ALF2=ALF(2)                                                           INTC1460
      PHI1=PHI(1)                                                           INTC1470
      PHI2=PHI(2)                                                           INTC1480
C CALCULATES TWO ALF & PHI ANGLES FOR 'I' & 'III'                           INTC1490
      CALL INTSCS(XPA,XPC,ZPC,XPUP,XRIN,                                    INTC1500
     1CPA,CPE,PHI,ALF,XAX,YAX,ZAX,                                          INTC1510
     2XAX,YAA,ZAA,XA,YA,ZA,XA,YA,ZA,NY,NX,IEPS)                             INTC1520
      IEPS2=IEPS                                                            INTC1530
      ALF3=ALF(1)                                                           INTC1540
      ALF4=ALF(2)                                                           INTC1550
      PHI3=PHI(1)                                                           INTC1560
      PHI4=PHI(2)                                                           INTC1570
C SELECTS THE PROPER ALF & PHI ANGLES OUT OF THE FOUR VALUES                INTC1580
      FALF=((ALF1+ALF2+ALF3+ALF4)-AMAX1(ALF1,ALF2,ALF3,                     INTC1590
     1ALF4)-AMIN1(ALF1,ALF2,ALF3,ALF4))/2                                   INTC1600
      FPHI=((PHI1+PHI2+PHI3+PHI4)-AMAX1(PHI1,PHI2,PHI3,PHI4)                INTC1610
     1-AMIN1(PHI1,PHI2,PHI3,PHI4))/2                                        INTC1620
C CALCULATES NEW PS FROM DATA OF POSITION IV                                INTC1630
      ALFCN=FALF-XPU                                                        INTC1640
      CALL INTPLT(XA,YA,ZA,ALFCN,FPHI,NX,NY,CPU)                            INTC1650
      ALFCN=FALF-XPC                                                        INTC1660
      CALL INTPLT(XA,YA,ZA,ALFCN,FPHI,NX,NY,CPC)                            INTC1670
      PSN=(PPC*CPU-PPU*CPC)/(CPU-CPC)                                       INTC1680
C CONVERGENCE TESTS                                                         INTC1690
      EPSPS=ABS((PSN-PS)/PS)                                                INTC1700
      EPSPSC=.000000000009*(PT**2.0)-.000)0098*PT                           INTC1710
      IF(IEPS1.EQ.2) EPSPSC=.000000000009*(PT**2.0)-.0000006*PT             INTC1720
      IF(IEPS2.EQ.2) EPSPSC=.000000000009*(PT**2.0)-.0000006*PT             INTC1730
      IF(EPSPS.GT.EPSPSC) GO TO 310                                         INTC1740
      GO TO 309                                                             INTC1750
310   IIT=IIT+1                                                             INTC1760
      IF(IIT.GT.10) GO TO 180                                               INTC1770
      PS=PS+RELAPS*(PSN-PS)                                                 INTC1780
      PSC=PS                                                                INTC1790
      PST=PS                                                                INTC1800
      GO TO 300                                                             INTC1810
303   WRITE(6,171) FALF                                                     INTC1820
171   FORMAT('0',' VELOCITY YAW IS' ,F15.2)                                 INTC1830
      WRITE(6,172) FPHI                                                     INTC1840
172   FORMAT(' VELOCITY PITCH IS' ,F15.2)                                   INTC1850
      WRITE(6,173) PSC                                                      INTC1860
173   FORMAT(' STATIC PRESSURE IS' ,F15.3)                                  INTC1870
      WRITE(6,174) PT                                                       INTC1880
174   FORMAT(' TOTAL PRESSURE IS' ,F15.3)                                   INTC1890
      AM=SQRT((PT/PSC)**0.285714-1.0)*5.0)                                  INTC1900
      WRITE(6,175) AM                                                       INTC1910
175   FORMAT(' MACH NUMBER IS' ,F15.5)                                      INTC1920
CT    CALL IAGLN(A)                                                         INTC1930
CT    VIRTIM=(A(5)-IA5C)/76800                                              INTC1940
CT    CPU=(A(6)-IA6C)/76800                                                 INTC1950
CT    WRITE(6,450) VIRTIM                                                   INTC1960
450   FORMAT(' VIRTUAL TIME IS' ,F15.5)                                     INTC1970
CT    WRITE(6,451) CPU                                                      INTC1980
451   FORMAT(' TOTAL CPU IS' ,F15.5)                                        INTC1990
CT    IA5C=A(5)                                                             INTC2000
CT    IA6C=A(6)                                                             INTC2010
      GO TO 193                                                             INTC2020
305   WRITE(6,307)                                                          INTC2030
307   FORMAT(' SCANNED 1000 TIMES')                                         INTC2040
      GO TO 193                                                             INTC2050
      END                                                                   INTC2060
      SUBROUTINE INTSCS(XRP1,XRP2,ARLD,XPUP,XRIN,                           INTC2070
     1HT1,HT2,RES1,RES2,X1,Y1,Z1,                                           INTC2080
     2X2,Y2,Z2,A3,Y3,Z3,A4,Y4,Z4,N1,N2,IEPS)                                INTC2090
      DIMENSION RES1(40),RES2(40),S1-ES(10),X1(40),Y1(40),                  INTC2100
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FILE: VOR      FORTRAN P1                    N     P              S

      1Z1(40,40),X2(40),Y2(40),Z2(40,40),X3(40),Y3(40),                 INTC2110
     2Z3(40,40),X4(40),Y4(40),Z4(40,40)                                 INTC2120
      RES1(1)=5000.                                                     INTC2130
      RES1(2)=5000.                                                     INTC2140
      RES2(1)=9000.                                                     INTC2150
      RES2(2)=9000.                                                     INTC2160
      IEPS=1                                                            INTC2170
      ISL=1                                                             INTC2180
      ISR=1                                                             INTC2190
      DAR=1.                                                            INTC2200
      AR2R=AR1A                                                         INTC2210
      GO TO 152                                                         INTC2220
150   AR2R=AR2R+DAR                                                     INTC2230
      AR2RJ=AR2R                                                        INTC2240
152   ARM1=AR2R-ARP1                                                    INTC2250
      ARM2=AR2R-ARP2                                                    INTC2260
C CHECK FOR LOWER CALIBRATION RANGE                                     INTC2270
      IF(ARM1.LT.ARLO) GO TO 150                                        INTC2280
      IF(ARM2.LT.ARLO) GO TO 150                                        INTC2290
      K=1                                                               INTC2300
C CALCULATES INITIAL PENETRATION POINTS                                 INTC2310
      CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                        INTC2320
      RAJL=ARRES(1)                                                     INTC2330
      RAJR=ARRES(2)                                                     INTC2340
      CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,ARM2,ARRES)                        INTC2350
      RBJL=ARRES(1)                                                     INTC2360
      RBJR=ARRES(2)                                                     INTC2370
C CALCULATES SUCCESIVE PENETRATION POINTS                               INTC2380
      DO 140 I=1,10000                                                  INTC2390
      AR2R=AR2R+DAR                                                     INTC2400
      ARM1=AR2R-ARP1                                                    INTC2410
      ARM2=AR2R-ARP2                                                    INTC2420
C CHECK FOR UPPER CALIBRATION RANGE                                     INTC2430
      IF(ARM1.GT.ARUP) GO TO 195                                        INTC2440
      IF(ARM2.GT.ARUP) GO TO 195                                        INTC2450
      CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                        INTC2460
      RAIL=ARRES(1)                                                     INTC2470
      RAIR=ARRES(2)                                                     INTC2480
      CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,ARM2,ARRES)                        INTC2490
      RBIL=ARRES(1)                                                     INTC2500
      RBIR=ARRES(2)                                                     INTC2510
      IF(RAJL.EQ.1000.) ISL=10                                          INTC2520
      IF(RAJL.EQ.1000.) ISL=10                                          INTC2530
      IF(RBJR.EQ.1000.) ISR=10                                          INTC2540
      IF(RAJR.EQ.1000.) ISR=10                                          INTC2550
      IF(RAIL.EQ.1000.) ISL=10                                          INTC2560
      IF(RBIL.EQ.1000.) ISL=10                                          INTC2570
      IF(RBIR.EQ.1000.) ISR=10                                          INTC2580
      IF(RAIR.EQ.1000.) ISR=10                                          INTC2590
C CHECK FOR DIRECT HIT ON LEFT INTERSECTION,EVALUATE IF REQUIRED         INTC2600
      IF(ISL.NE.10) GO TO 164                                           INTC2610
      ISL=1                                                             INTC2620
      GO TO 184                                                         INTC2630
164   IF(RAIL.NE.RBIL) GO TO 180                                        INTC2640
      RES1(K)=RBIL                                                      INTC2650
      RES2(K)=AR2R                                                      INTC2660
      IF(K.EQ.2) GO TO 155                                              INTC2670
      K=2                                                               INTC2680
      GO TO 184                                                         INTC2690
C CHECK FOR INTERMEDIATE LEFT INTERSECTION,EVALUATE IF REQUIRED         INTC2700
180   IF(ISL.NE.10) GO TO 160                                           INTC2710
      ISL=1                                                             INTC2720
      GO TO 184                                                         INTC2730
160   IF((RAJL-RBJL)/(RAIL-RBIL).GT.0.0) GO TO 184                      INTC2740
      AA=(AR2RJ-AR2R)/(RAJL-RAIL)                                       INTC2750
      BA=AR2R-AA*RAIL                                                   INTC2760
      AB=(AR2RJ-AR2R)/(RBJL-RBIL)                                       INTC2770
      BB=AR2R-AB*RBIL                                                   INTC2780
      RES1(K)=(BB-BA)/(AA-AB)                                           INTC2790
      RES2(K)=AA*RES1(K)+BA                                             INTC2800
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FILE: VDR       FORTRAN  01                    N     P              S

      IF(K.EQ.2) GO TO 155                                                  INTC2810
      K=2                                                                   INTC2820
C CHECK FOR DIRECT HIT OR RIGHT INTERSECTION,EVALUATE IF REQUIRED           INTC2830
183   IF(ISR.NE.1) GO TO 161                                                INTC2840
      ISR=1                                                                 INTC2850
      GO TO 163                                                             INTC2860
161   IF(RAIR.NE.RBIR) GO TO 182                                            INTC2870
      RES1(K)=RBIR                                                          INTC2880
      RES2(K)=AR2R                                                          INTC2890
      IF(K.EQ.2) GO TO 155                                                  INTC2900
      K=2                                                                   INTC2910
      GO TO 163                                                             INTC2920
C CHECK FOR INTERMEDIATE RIGHT INTERSECTION,EVALUATE IF REQUIRED            INTC2930
182   IF(ISR.NE.1) GO TO 162                                                INTC2940
      ISR=1                                                                 INTC2950
      GO TO 163                                                             INTC2960
162   IF((RAJR-RBJR)/(RAIR-RBIR).GT.0.0) GO TO 163                          INTC2970
      AA=(AR2RJ-AR2R)/(RAJR-RAIR)                                           INTC2980
      BA=AR2R-AA*RAIR                                                       INTC2990
      AB=(AR2RJ-AR2R)/(RBJR-RBIR)                                           INTC3000
      BB=AR2R-AB*RBIR                                                       INTC3010
      RES1(K)=(BB-BA)/(AA-AB)                                               INTC3020
      RES2(K)=AA*RES1(K)+BA                                                 INTC3030
      IF(K.EQ.2) GO TO 155                                                  INTC3040
      K=2                                                                   INTC3050
C RE-INITIATE                                                               INTC3060
163   AR2RJ=AR2R                                                            INTC3070
      RAJL=RAIL                                                             INTC3080
      RAJR=RAIR                                                             INTC3090
      RBJL=RBIL                                                             INTC3100
140   RBJR=RBIR                                                             INTC3110
      WRITE(6,210)                                                          INTC3120
210   FORMAT(' LOOP 140 THROUGH,NO POINTS FOUND')                           INTC3130
      GO TO 155                                                             INTC3140
195   IF(RES1(1).EQ.9000.0) GO TO 191                                       INTC3150
      IF(RES1(2).EQ.9000.0) GO TO 191                                       INTC3160
      IF(RES2(1).EQ.9000.0) GO TO 191                                       INTC3170
      IF(RES2(2).EQ.9000.0) GO TO 191                                       INTC3180
      GO TO 155                                                             INTC3190
C EVALUATION OF INTERSECTIONS WHEN CURVES ARE ALMOST TANGENT                INTC3200
191   YGO=0.0                                                               INTC3210
      IEPS=2                                                                INTC3220
      CALL PEMPTS(NZ,N1,X3,Y3,Z3,HT1,YGO,ARRES)                             INTC3230
      R1=ABS(ARRES(2)-ARRES(1))/2                                           INTC3240
      CALL PEMPTS(NZ,N1,X4,Y4,Z4,HT2,YGO,ARRES)                             INTC3250
      R2=ABS(ARRES(2)-ARRES(1))/2                                           INTC3260
      RES2(1)=((R1**2)-(R2**2)+(ARP2**2))/(2.0*ARP2)                        INTC3270
      RES2(2)=RES2(1)                                                       INTC3280
      RES1(1)=SQRT(ABS((R1**2)-(RES2(1)**2)))                               INTC3290
      RES1(2)=-RES1(1)                                                      INTC3300
155   RETURN                                                                INTC3310
      END                                                                   INTC3320
      SUBROUTINE PEMPTS(NX,NY,X,Y,Z,HT,YG,XR)                               INTC3330
      DIMENSION Y(40),ZX(40),Z(40,40),X(40),XR(10)                          INTC3340
      IR=1                                                                  INTC3350
C SEARCH FOR J OF LOWER Y LINE                                              INTC3360
      DO 101 I=1,NY                                                         INTC3370
      IF (Y(I).GE.YG) GO TO 102                                             INTC3380
101   CONTINUE                                                              INTC3390
102   J=I-1                                                                 INTC3400
C COARSE SCAN FOR ZERO PASS                                                 INTC3410
C NEXT 4 LINES ARE EXECUTED IN FIRST SEARCH ONLY                            INTC3420
      XC=(YG-Y(J))/(Y(J+1)-Y(J))                                            INTC3430
      ZX(1)=(Z(1,J+1)-Z(1,J))*XC+Z(1,J)                                     INTC3440
      IF(ZX(1).EQ.HT) GO TO 107                                             INTC3450
      I3=2                                                                  INTC3460
112   DO 103 I=I3,NX                                                        INTC3470
      ZX(I)=(Z(I,J+1)-Z(I,J))*XC+Z(I,J)                                     INTC3480
      ZM=(Z(I,J+1)-Z(I-1,J))*(YG-Y(J))/(Y(J+1)-Y(J))+Z(I-1,J)               INTC3490
      IF(ZX(I).EQ.HT) GO TO 108                                             INTC3500
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FILE: VOR      FORTRAN P1                    N     P              S

      IF((ZX(I-1)-HT)/(ZX(I)-HT).LT.0.0) GO TO 104                          INT03510
103   CONTINUE                                                              INT03520
      GO TO 110                                                             INT03530
C CALCULATION OF PENETRATIONS IN EITHER TRIANGLE                            INT03540
104   XM=X(I-1)+(X(I)-X(I-1))*(YG-Y(J))/(Y(J+1)-Y(J))                       INT03550
      IF(ZM.EQ.HT) GO TO 105                                                INT03560
      IF((ZX(I)-HT)/(ZM-HT).LT.0.0) GO TO 105                               INT03570
      DD=ABS(HT-ZM)+ABS(ZX(I-1)-HT)                                         INT03580
      XS=X(I-1)+(XM-X(I-1))*ABS(ZX(I-1)-HT)/DD                              INT03590
      GO TO 110                                                             INT03600
105   XS=XM+(X(I)-XM)*ABS(ZM-HT)/(ABS(ZM-HT)+ABS(ZX(I)-HT))                 INT03610
      GO TO 110                                                             INT03620
C LOGICAL PENETRATIONS ACCUMULATION                                         INT03630
107   XR(1)=X(1)                                                            INT03640
      I=1                                                                   INT03650
      GO TO 113                                                             INT03660
108   XR(IR)=X(I)                                                           INT03670
      GO TO 111                                                             INT03680
110   XR(IR)=XS                                                             INT03690
111   IF(IR.EQ.2) GO TO 114                                                 INT03700
113   IR=2                                                                  INT03710
      IB=I+1                                                                INT03720
      GO TO 116                                                             INT03730
116   IF(IR.EQ.1) GO TO 117                                                 INT03740
      XR(2)=1000.0                                                          INT03750
      GO TO 114                                                             INT03760
117   XR(1)=1000.0                                                          INT03770
      XR(2)=1000.0                                                          INT03780
114   RETURN                                                                INT03790
      END                                                                   INT03800
      SUBROUTINE INTPL1(X,Y,Z,XG,YG,NX,NY,ZRES)                             INT03810
C LINEAR INTERPOLATION ON CALIBRATION SURFACE TO EVALUATE                   INT03820
C CP VALUE AT CG-COORDINATES XG,YG.THE RESULT RETURNED IS ZRES              INT03830
      DIMENSION X(40),Y(40),Z(40,40)                                        INT03840
C SEARCH FOR I OF LEFT X LINE                                               INT03850
      DO 1 IC=1,NX                                                          INT03860
      IF(X(IC).GE.XG) GO TO 2                                               INT03870
1     CONTINUE                                                              INT03880
2     I=IC-1                                                                INT03890
C SEARCH FOR J OF LOWER Y LINE                                              INT03900
      DO 3 JC=1,NY                                                          INT03910
      IF(Y(JC).GE.YG) GO TO 4                                               INT03920
3     CONTINUE                                                              INT03930
4     J=JC-1                                                                INT03940
      AL=(Y(J+1)-Y(J))/(X(I+1)-X(I))                                        INT03950
      BL=Y(J)-AL*X(I)                                                       INT03960
      YCR=(AL*XG)+BL                                                        INT03970
      IF(YG.EQ.YCR) GO TO 7                                                 INT03980
      IF(YG.LT.YCR) GO TO 5                                                 INT03990
C RESULTING Z IS IN LOWRER TRIANGLE                                         INT04000
      X3=X(I+1)                                                             INT04010
      Y3=Y(J)                                                               INT04020
      Z3=Z(I+1,J)                                                           INT04030
      GO TO 6                                                               INT04040
C RASULTING Z IS IN UPPER TRIANGLE                                          INT04050
5     X3=X(I)                                                               INT04060
      Y3=Y(J+1)                                                             INT04070
      Z3=Z(I,J+1)                                                           INT04080
C GENERAL CALCULATION:GOOD FOR BOTH TRIANGLES                               INT04090
6     X1=X(I)                                                               INT04100
      Y1=Y(J)                                                               INT04110
      Z1=Z(I,J)                                                             INT04120
      X2=X(I+1)                                                             INT04130
      Y2=Y(J+1)                                                             INT04140
      Z2=Z(I+1,J+1)                                                         INT04150
      AP=((Z1-Z3)*(Y1-Y2)-(Z1-Z2)*(Y1-Y3))/((X1-X3)*(Y1-Y2)-(X1-X2)         INT04160
     1*(Y1-Y3))                                                             INT04170
      BP=((Z1-Z2)-AP*(X1-X2))/(Y1-Y2)                                       INT04180
      CP=Z1-AP*X1-BP*Y1                                                     INT04190
      ZRES=AP*XG+BP*YG+CP                                                   INT04200
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FILE: VDR      FORTRAN P1                    N     P              S

      GO TO 100                                                          INTC4210
C RESULTING Z IS ON DIVIDING LINE                                        INTC4220
7     ZRES=(Z(I+1,J+1)-Z(I,J))*(XG-X(I))/(X(I+1)-X(I))+Z(I,J)            INTC4230
100   RETURN                                                             INTC4240
      END                                                                INTC4250
      SUBROUTINE MAXARY(Z,ZMAX,NX,NY)                                    INTC4260
C EVALUATION OF MAXIMUM OF CALIBRATION SURFACE MATRIX                    INTC4270
      DIMENSION Z(40,40)                                                 INTC4280
      DO 1 I=1,NX                                                        INTC4290
      DO 1 J=1,NY                                                        INTC4300
1     IF(Z(I,J).GE.ZMAX) ZMAX=Z(I,J)                                     INTC4310
      RETURN                                                             INTC4320
      END                                                                INTC4330
      SUBROUTINE MINARY(Z,ZMIN,NX,NY)                                    INTC4340
C EVALUATION OF MINIMUM OF CALIBRATION SURFACE MATRIX                    INTC4350
      DIMENSION Z(40,40)                                                 INTC4360
      DO 1 I=1,NX                                                        INTC4370
      DO 1 J=1,NY                                                        INTC4380
1     IF(Z(I,J).LE.ZMIN) ZMIN=Z(I,J)                                     INTC4390
      RETURN                                                             INTC4400
      END                                                                INTC4410
C END OF VDR                                                             INTC4420
                                                                         INTC4430
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APPENDIX 2

LISTING OF SWVDR

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  07/06/75  16.45.15

FILE: SAVER     FORTRAN  P1                    N     P              S

C  START OF SAVOR                                                          INTC0010
      DIMENSION ALF(10),PHI(10),XA(40),YA(40),                             INTC0020
     1ZA(40,40),XB(40),YB(40),ZB(40,40),XAX(40),YAX(40),                   INTC0030
     2ZAX(40,40),XBX(40),YBX(40),ZBX(40,40)                                INTC0040
119   FORMAT(2I5)                                                          INTC0050
131   FORMAT(F7.1)                                                         INTC0060
130   FORMAT(F5.1)                                                         INTC0070
120   FORMAT(F8.5)                                                         INTC0080
132   FORMAT(F10.5)                                                        INTC0090
135   FORMAT(F15.5)                                                        INTC0100
136   FORMAT(F17.5)                                                        INTC0110
C READ PROBE CALIBRATION DATA                                              INTC0120
      READ(2,119) NX,NY                                                    INTC0130
      DO 121 I=1,NX                                                        INTC0140
      READ(2,130) XA(I)                                                    INTC0150
121   CONTINUE                                                             INTC0160
      DO 122 I=1,NY                                                        INTC0170
      READ(2,130) YA(I)                                                    INTC0180
122   CONTINUE                                                             INTC0190
      DO 123 I=1,NX                                                        INTC0200
      DO 123 J=1,NY                                                        INTC0210
      READ(2,120) ZA(I,J)                                                  INTC0220
123   CONTINUE                                                             INTC0230
      DO 221 I=1,NX                                                        INTC0240
      READ(2,130) XB(I)                                                    INTC0250
221   CONTINUE                                                             INTC0260
      DO 222 I=1,NY                                                        INTC0270
      READ(2,130) YB(I)                                                    INTC0280
222   CONTINUE                                                             INTC0290
      DO 223 I=1,NX                                                        INTC0300
      DO 223 J=1,NY                                                        INTC0310
      READ(2,120) ZB(I,J)                                                  INTC0320
223   CONTINUE                                                             INTC0330
C TRANSFORM CALIBRATION MATRICES                                           INTC0340
      DO 224 I=1,NY                                                        INTC0350
224   XAX(I)=YA(I)                                                         INTC0360
      DO 225 I=1,NX                                                        INTC0370
225   YAX(I)=XA(I)                                                         INTC0380
      DO 226 I=1,NY                                                        INTC0390
      DO 226 J=1,NX                                                        INTC0400
226   ZAX(I,J)=ZA(J,I)                                                     INTC0410
      DO 227 I=1,NY                                                        INTC0420
227   XBX(I)=YB(I)                                                         INTC0430
      DO 228 I=1,NX                                                        INTC0440
228   YBX(I)=XB(I)                                                         INTC0450
      DO 229 I=1,NY                                                        INTC0460
      DO 229 J=1,NX                                                        INTC0470
229   ZBX(I,J)=ZB(J,I)                                                     INTC0480
C PROBE SETTINGS                                                           INTC0490
      YPA=0.0                                                              INTC0500
      YPB=55.                                                              INTC0510
      XPA=0.0                                                              INTC0520
      XPC=20.                                                              INTC0530
      XPD=-20.                                                             INTC0540
C PROGRAM CONSTANTS                                                        INTC0550
      YRLO=-30.                                                            INTC0560
      YRUP=30.                                                             INTC0570
      YRIN=-30.                                                            INTC0580
      XRLO=-30.                                                            INTC0590
      XRUP=30.                                                             INTC0600
      XRIN=-30.                                                            INTC0610
      ICOPS=1                                                              INTC0620
      NCOCPS=2                                                             INTC0630
      NOSIM=2                                                              INTC0640
      IIT=1                                                                INTC0650
      ISCAN=1                                                              INTC0660
      RELXPS=0.0                                                           INTC0670
C EXPERIMENT SIMULATION                                                    INTC0680
153   CONTINUE                                                             INTC0690
401   FORMAT(F15.4)                                                        INTC0700
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      READ(5,401) PT                                                    INTCC710
      WRITE(6,401) PT                                                   INTCC720
      IF(NOSIM.EQ.2) GO TO 500                                          INTCC730
      READ(5,401) PS                                                    INTCC740
      WRITE(6,401) PS                                                   INTCC750
      READ(5,401) ALFA                                                  INTCC760
      WRITE(6,401) ALFA                                                 INTCC770
      READ(5,401) PHII                                                  INTCC780
      WRITE(6,401) PHII                                                 INTCC790
      CALL INTPLT(XA,YA,ZA,ALFA,PHII,NX,NY,CPA)                         INTCC800
      ALFC=ALFA-APC                                                     INTCC810
      CALL INTPLT(XA,YA,ZA,ALFC,PHII,NX,NY,CPC)                         INTCC820
      ALFD=ALFA-APC                                                     INTCC830
      CALL INTPLT(XA,YA,ZA,ALFD,PHII,NX,NY,CPD)                         INTCC840
      PHIB=PHII-YPB                                                     INTCC850
      CALL INTPLT(XB,YB,ZB,ALFA,PHIB,NX,NY,CPB)                         INTCC860
      PDYN=PT-PS                                                        INTCC870
      PPA=CPA*PDYN+PS                                                   INTCC880
      PPB=CPB*PDYN+PS                                                   INTCC890
      PPC=CPC*PDYN+PS                                                   INTCC900
      PPD=CPD*PDYN+PS                                                   INTCC910
C READ MEASUREMENTS DATA                                                INTCC920
      IF(NOSIM.EQ.1) GO TO 501                                          INTCC930
500   READ(5,135) PPA                                                   INTCC940
      WRITE(6,136) PPA                                                  INTCC950
      READ(5,135) PPB                                                   INTCC960
      WRITE(6,136) PPB                                                  INTCC970
      READ(5,135) PPC                                                   INTCC980
      WRITE(6,136) PPC                                                  INTCC990
      READ(5,135) PPD                                                   INTC1000
      WRITE(6,136) PPD                                                  INTC1010
501   READ(5,135) PSIN                                                  INTC1020
      WRITE(6,136) PSIN                                                 INTC1030
      IF(ISCAN.EQ.1) GO TO 181                                          INTC1040
180   IF(ISCAN.GT.1000) GO TO 305                                       INTC1050
      III=1                                                             INTC1060
      ICCPS=1                                                           INTC1070
      ISCAN=ISCAN+1                                                     INTC1080
      PSIN=PSIN+5.0                                                     INTC1090
      WRITE(6,136) PSIN                                                 INTC1100
181   CONTINUE                                                          INTC1110
      PS=PSIN                                                           INTC1120
      PSC=PSIN                                                          INTC1130
      PST=PS                                                            INTC1140
C CALCULATES PRESSURE COEFFICIENTS                                      INTC1150
300   CONTINUE                                                          INTC1160
      PDYN=PT-PS                                                        INTC1170
      CPA=(PPA-PS)/PDYN                                                 INTC1180
      CPB=(PPB-PS)/PDYN                                                 INTC1190
      CPC=(PPC-PS)/PDYN                                                 INTC1200
      CPD=(PPD-PS)/PDYN                                                 INTC1210
C CORRECTS PS ASSUMPTION TO ENSURE CP ARE IN CALIBRATION RANGE          INTC1220
      IF(NOCOPS.EQ.2) GO TO 301                                         INTC1230
      ZAMAX=-10000.                                                     INTC1240
      CALL MAXARY(ZA,ZAMAX,NX,NY)                                       INTC1250
      IF(CPA.GT.ZAMAX) PSC=1.01*PS                                      INTC1260
      IF(CPC.GT.ZAMAX) PSC=1.01*PS                                      INTC1270
      IF(CPD.GT.ZAMAX) PSC=1.01*PS                                      INTC1280
      ZBMAX=-10000.                                                     INTC1290
      CALL MAXARY(ZB,ZBMAX,NX,NY)                                       INTC1300
      IF(CPB.GT.ZBMAX) PSC=1.01*PS                                      INTC1310
      ZAMIN=10000.                                                      INTC1320
      CALL MINARY(ZA,ZAMIN,NX,NY)                                       INTC1330
      IF(CPA.LT.ZAMIN) PSC=0.99*PS                                      INTC1340
      IF(CPC.LT.ZAMIN) PSC=0.99*PS                                      INTC1350
      IF(CPD.LT.ZAMIN) PSC=0.99*PS                                      INTC1360
      ZBMIN=10000.                                                      INTC1370
      CALL MINARY(ZB,ZBMIN,NX,NY)                                       INTC1380
      IF(CPB.LT.ZBMIN) PSC=0.99*PS                                      INTC1390
      IF(PSC.EQ.PST) GO TO 301                                          INTC1400
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      ICOPS=ICOPS+1                                                     INTC1410
      IF(ICOPS.GT.10) GO TO 180                                         INTC1420
      PS=PSC                                                            INTC1430
      PST=PSC                                                           INTC1440
      GO TO 300                                                         INTC1450
301   CONTINUE                                                          INTC1460
C CALCULATES INT ALF & PHI ANGLES FOR 'I' & 'II'                        INTC1470
      CALL INTSCS(XPA,YPA,YRLO,YRUP,YRIN,                               INTC1480
     1CPA,CPB,ALF,PHI,XA,YA,ZA,                                         INTC1490
     2XB,YB,ZB,XAX,YAX,ZAX,XBX,YBX,ZBX,NX,NY)                           INTC1500
      ALF1=ALF(1)                                                       INTC1510
      ALF2=ALF(2)                                                       INTC1520
      PHI1=PHI(1)                                                       INTC1530
      PHI2=PHI(2)                                                       INTC1540
C CALCULATES INT ALF & PHI ANGLES FOR 'I' & 'III'                       INTC1550
      CALL INTSCS(XPA,XPC,XRLO,XRUP,XRIN,                               INTC1560
     1CPA,CPC,PHI,ALF,XAX,YAX,ZAX,                                      INTC1570
     2XAX,YAX,ZAX,XA,YA,ZA,XA,YA,ZA,NY,NX)                              INTC1580
      ALF3=ALF(1)                                                       INTC1590
      ALF4=ALF(2)                                                       INTC1600
      PHI3=PHI(1)                                                       INTC1610
      PHI4=PHI(2)                                                       INTC1620
C SELECTS THE PROPER ALF & PHI ANGLES OUT OF THE FOUR VALUES            INTC1630
      ALF=((ALF1+ALF2+ALF3+ALF4)-AMAX1(ALF1,ALF2,ALF3,                  INTC1640
     1ALF4)-AMIN1(ALF1,ALF2,ALF3,ALF4))/2                               INTC1650
      FPHI=((PHI1+PHI2+PHI3+PHI4)-AMAX1(PHI1,PHI2,PHI3,PHI4)            INTC1660
     1-AMIN1(PHI1,PHI2,PHI3,PHI4))/2                                    INTC1670
C CALCULATES NEW PS FROM DATA OF POSITION D AND CORRECTS PT             INTC1680
      ALFDN=ALF-XPD                                                     INTC1690
      CALL INTPLT(XA,YA,ZA,ALFDN,FPHI,NX,NY,CPD)                        INTC1700
      ALFDN=ALF-XPC                                                     INTC1710
      CALL INTPLT(XA,YA,ZA,ALFDN,FPHI,NX,NY,CPC)                        INTC1720
      PSN=(PPC*CPD-PPD*CPC)/(CPD-CPC)                                   INTC1730
907   WRITE(6,911)III,ALF,FPHI,PSN                                      INTC1740
911   FORMAT(' ITERATION VALUES',I5,10X,2F6.2,F10.2)                    INTC1750
C CONVERGENCE TESTS                                                     INTC1760
      EPSPS=ABS((PSN-PS)/PS)                                            INTC1770
      EPSPSG=.000000J0C009*(PT**2.0)-.0000098*PT                        INTC1780
      IF(IEPS1.EQ.2) EPSPSG=.0000000C009*(PT**2.0)-.0000038*PT          INTC1790
      IF(IEPS2.EQ.2) EPSPSG=.000000000J9*(PT**2.0)-.0000CE*PT           INTC1800
      IF(EPSPS.GT.EPSPSG) GO TO 310                                     INTC1810
      GO TO 303                                                         INTC1820
310   CONTINUE                                                          INTC1830
      III=III+1                                                         INTC1840
      IF(III.GT.10) GO TO 180                                           INTC1850
      PS=PS+RELXPS*(PSN-PS)                                             INTC1860
      PSC=PS                                                            INTC1870
      PST=PS                                                            INTC1880
      GO TO 300                                                         INTC1890
303   WRITE(6,171) FALF                                                 INTC1900
171   FORMAT('0',' VELOCITY YAW IS' ,F15.2)                             INTC1910
      WRITE(6,172) FPHI                                                 INTC1920
172   FORMAT(' VELOCITY PITCH IS' ,F15.2)                               INTC1930
      WRITE(6,173) PSN                                                  INTC1940
173   FORMAT(' STATIC PRESSURE IS' ,F15.3)                              INTC1950
      WRITE(6,174) PT                                                   INTC1960
174   FORMAT(' TOTAL PRESSURE IS' ,F15.3)                               INTC1970
      AM=SQRT(((PT/PSN)**0.285714-1.0)*5.0)                             INTC1980
      WRITE(6,175) AM                                                   INTC1990
175   FORMAT(' MACH NUMBER IS' ,F15.5)                                  INTC2000
      GO TO 195                                                         INTC2010
305   WRITE(6,307)                                                      INTC2020
307   FORMAT(' SCANNED 1000 TIMES')                                     INTC2030
      GO TO 195                                                         INTC2040
      END                                                               INTC2050
      SUBROUTINE INTSCS(ARP1,ARP2,ARLO,ARUP,ARIN,                       INTC2060
     1HT1,HT2,RES1,RES2,XA,YA,ZA,                                       INTC2070
     2X2,Y2,Z2,X3,Y3,Z3,X4,Y4,Z4,N1,N2)                                 INTC2080
      DIMENSION RES1(10),RES2(10),ARRES(10),X1(40),Y1(40),              INTC2090
     1Z1(40,40),X2(40),Y2(40),Z2(40,40),X3(40),Y3(40),                  INTC2100
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FILE: SAVCR    FORTRAN  P1                    N     P              S

      2ZJ(40,40),X4(40),Y4(40),Z4(40,40)                                INTC2110
       RES1(1)=9000.                                                    INTC2120
       RES1(2)=9000.                                                    INTC2130
       RES2(1)=9000.                                                    INTC2140
       RES2(2)=9000.                                                    INTC2150
       ISL=1                                                            INTC2160
       ISR=1                                                            INTC2170
       DAR=1.                                                           INTC2180
       AR2R=ARIN                                                        INTC2190
       GO TO 152                                                        INTC2200
150    AR2R=AR2R+DAR                                                    INTC2210
       AR2RJ=AR2R                                                       INTC2220
152    ARM1=AR2R-ARP1                                                   INTC2230
       ARM2=AR2R-ARP2                                                   INTC2240
C CHECK FOR LOWER CALIBRATION RANGE                                     INTC2250
       IF(ARM1.LT.ARLO) GO TO 150                                       INTC2260
       IF(ARM2.LT.ARLO) GO TO 150                                       INTC2270
       K=1                                                              INTC2280
C CALCULATES INITIAL PENETRATION POINTS                                 INTC2290
       CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                       INTC2300
       RAJL=ARRES(1)                                                    INTC2310
       RAJR=ARRES(2)                                                    INTC2320
       CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,ARM2,ARRES)                       INTC2330
       RBJL=ARRES(1)                                                    INTC2340
       RBJR=ARRES(2)                                                    INTC2350
C CALCULATES SUCCESIVE PENETRATION POINTS                               INTC2360
       DO 140 I=1,10000                                                 INTC2370
       AR2R=AR2R+DAR                                                    INTC2380
       ARM1=AR2R-ARP1                                                   INTC2390
       ARM2=AR2R-ARP2                                                   INTC2400
C CHECK FOR UPPER CALIBRATION RANGE                                     INTC2410
       IF(ARM1.GT.ARUP) GO TO 195                                       INTC2420
       IF(ARM2.GT.ARUP) GO TO 195                                       INTC2430
       CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                       INTC2440
       RAIL=ARRES(1)                                                    INTC2450
       RAIR=ARRES(2)                                                    INTC2460
       CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,ARM2,ARRES)                       INTC2470
       RBIL=ARRES(1)                                                    INTC2480
       RBIR=ARRES(2)                                                    INTC2490
       IF(RAJL.EQ.1000.) ISL=10                                         INTC2500
       IF(REJL.EQ.1000.) ISL=10                                         INTC2510
       IF(RBJR.EQ.1000.) ISR=10                                         INTC2520
       IF(RAJR.EQ.1000.) ISR=10                                         INTC2530
       IF(RAIL.EQ.1000.) ISL=10                                         INTC2540
       IF(RBIL.EQ.1000.) ISL=10                                         INTC2550
       IF(RBIR.EQ.1000.) ISR=10                                         INTC2560
       IF(RAIR.EQ.1000.) ISR=10                                         INTC2570
C CHECK FOR DIRECT HIT OR LEFT INTERSECTION,EVALUATE IF REQUIRED        INTC2580
       IF(ISL.NE.10) GO TO 164                                          INTC2590
       ISL=1                                                            INTC2600
       GO TO 183                                                        INTC2610
164    IF(RAIL.NE.RBIL) GO TO 180                                       INTC2620
       RES1(K)=RBIL                                                     INTC2630
       RES2(K)=AR2R                                                     INTC2640
       IF(K.EQ.2) GO TO 155                                             INTC2650
       K=2                                                              INTC2660
       GO TO 183                                                        INTC2670
C CHECK FOR INTERMEDIATE LEFT INTERSECTION,EVALUATE IF REQUIRED         INTC2680
180    IF(ISL.NE.10) GO TO 160                                          INTC2690
       ISL=1                                                            INTC2700
       GO TO 183                                                        INTC2710
160    IF((RAJL-RBJL)/(RAIL-REIL).GT.0.0) GO TO 183                     INTC2720
       AA=(AR2RJ-AR2R)/(RAJL-RAIL)                                      INTC2730
       BA=AR2R-AA*RAIL                                                  INTC2740
       AB=(AR2RJ-AR2R)/(REJL-RBIL)                                      INTC2750
       BB=AR2R-AB*RBIL                                                  INTC2760
       RES1(K)=(BB-BA)/(AA-1B)                                          INTC2770
       RES2(K)=AA*RES1(K)+BA                                            INTC2780
       IF(K.EQ.2) GO TO 155                                             INTC2790
       K=2                                                              INTC2800
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C CHECK FOR DIRECT HIT OR RIGHT INTERSECTION,EVALUATE IF REQUIRED          INTC2810
183   IF(ISR.NE.10) GO TO 161                                              INTC2820
      ISR=1                                                                INTC2830
      GO TO 163                                                            INTC2840
161   IF(RAIR.NE.RBIR) GO TO 162                                           INTC2850
      RES1(K)=RBIR                                                         INTC2860
      RES2(K)=AR2R                                                         INTC2870
      IF(K.EQ.2) GO TO 155                                                 INTC2880
      K=2                                                                  INTC2890
      GO TO 163                                                            INTC2900
C CHECK FOR INTERMEDIATE RIGHT INTERSECTION,EVALUATE IF REQUIRED           INTC2910
162   IF(ISR.NE.10) GO TO 162                                              INTC2920
      ISR=1                                                                INTC2930
      GO TO 163                                                            INTC2940
162   IF((RAJR-RBJR)/(RAIR-RBIR).GT.0.0) GO TO 163                         INTC2950
      AA=(AR2RJ-AR2R)/(RAJR-RAIR)                                          INTC2960
      BA=AR2R-AA*RAIR                                                      INTC2970
      AB=(AR2RJ-AR2R)/(RBJR-RBIR)                                          INTC2980
      BB=AR2R-AB*RBIR                                                      INTC2990
      RES1(K)=(BB-BA)/(AA-AB)                                              INTC3000
      RES2(K)=AA*RES1(K)+BA                                                INTC3010
      IF(K.EQ.2) GO TO 155                                                 INTC3020
      K=2                                                                  INTC3030
C RE-INITIATE                                                              INTC3040
163   AR2RJ=AR2R                                                           INTC3050
      RAJL=RAIL                                                            INTC3060
      RAJR=RAIR                                                            INTC3070
      RBJL=RBIL                                                            INTC3080
      RBJR=RBIR                                                            INTC3090
140   CONTINUE                                                             INTC3100
      WRITE(6,210)                                                         INTC3110
210   FORMAT(' LOOP 140 THROUGH,NO POINTS FOUND')                          INTC3120
      GO TO 155                                                            INTC3130
195   IF(RES1(1).EQ.9000.0) GO TO 191                                      INTC3140
      IF(RES1(2).EQ.9000.0) GO TO 191                                      INTC3150
      IF(RES2(1).EQ.9000.0) GO TO 191                                      INTC3160
      IF(RES2(2).EQ.9000.0) GO TO 191                                      INTC3170
      GO TO 155                                                            INTC3180
C EVALUATION OF INTERSECTIONS WHEN CURVES ARE ALMOST TANGENT               INTC3190
191   YG=0.0                                                               INTC3200
      CALL PENPTS(N2,N1,X3,Y3,Z3,HT1,YG,ARRES)                             INTC3210
      R1=ABS(ARRES(2)-ARRES(1))/2                                          INTC3220
      CALL PENPTS(N2,N1,X4,Y4,Z4,HT2,YG,ARRES)                             INTC3230
      R2=ABS(ARRES(2)-ARRES(1))/2                                          INTC3240
      RES2(1)=((R1**2)-(R2**2)+(ARP2**2))/(2.0*ARP2)                       INTC3250
      RES2(2)=RES2(1)                                                      INTC3260
      RES1(1)=SQRT(ABS((R1**2)-(RES2(1)**2)))                              INTC3270
      RES1(2)=-RES1(1)                                                     INTC3280
155   RETURN                                                               INTC3290
      END                                                                  INTC3300
      SUBROUTINE PENPTS(NX,NY,X,Y,Z,HT,YG,XR)                              INTC3310
      DIMENSION Y(40),ZX(40),Z(40,40),X(40),XR(10)                         INTC3320
      IR=1                                                                 INTC3330
C SEARCH FOR J OF LOWER Y LINE                                             INTC3340
      DO 101 I=1,NY                                                        INTC3350
      IF (Y(I).GE.YG) GO TO 102                                            INTC3360
101   CONTINUE                                                             INTC3370
102   J=I-1                                                                INTC3380
C COLLAPSE SCAN FOR ZERO PASS                                              INTC3390
C NEXT 4 LINES ARE EXECUTED IN FIRST SEARCH ONLY                           INTC3400
      YC=(YG-Y(J))/(Y(J+1)-Y(J))                                           INTC3410
      ZX(1)=(Z(1,J+1)-Z(1,J))*YC+Z(1,J)                                    INTC3420
      IF(ZX(1).EQ.HT) GO TO 107                                            INTC3430
      I9=2                                                                 INTC3440
112   DO 103 I=I9,NX                                                       INTC3450
      ZX(I)=(Z(I,J+1)-Z(I,J))*YC+Z(I,J)                                    INTC3460
      ZA=(Z(I,J+1)-Z(I-1,J))*(YG-Y(J))/(Y(J+1)-Y(J))+Z(I-1,J)              INTC3470
      IF(ZX(I).EQ.HT) GO TO 108                                            INTC3480
      IF((ZX(I-1)-HT)/(ZX(I)-HT).LT.0.0) GO TO 104                         INTC3490
103   CONTINUE                                                             INTC3500
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      GO TO 116                                                          INTC3510
C CALCULATION OF PENETRATIONS IN EITHER TRIANGLE                         INTC3520
104   XM=X(I-1)+(X(I)-X(I-1))*(YG-Y(J))/(Y(J+1)-Y(J))                   INTC3530
      IF(ZM.E).HT) GO TO 105                                             INTC3540
      IF((ZX(I)-HT)/(ZM-HT).LT.0.0) GO TO 105                            INTC3550
      DD=ABS(HT-ZM)+ABS(ZX(I-1)-HT)                                      INTC3560
      XS=X(I-1)+(XM-X(I-1))*ABS(ZX(I-1)-HT)/DD                           INTC3570
      GO TO 110                                                          INTC3580
105   XS=XM+(X(I)-XM)*ABS(ZM-HT)/(ABS(ZM-HT)+ABS(ZX(I)-HT))              INTC3590
      GO TO 110                                                          INTC3600
C LOGICAL PENETRATIONS ACCUMULATION                                      INTC3610
107   XR(1)=X(1)                                                         INTC3620
      I=1                                                                INTC3630
      GO TO 113                                                          INTC3640
108   XR(IR)=X(I)                                                        INTC3650
      GO TO 111                                                          INTC3660
110   XR(IR)=XS                                                          INTC3670
111   IF(IS.EQ.2) GO TO 114                                              INTC3680
113   IR=2                                                               INTC3690
      I=I+1                                                              INTC3700
      GO TO 112                                                          INTC3710
116   IF(IF.EQ.1) GO TO 117                                              INTC3720
      XR(2)=1000.0                                                       INTC3730
      GO TO 114                                                          INTC3740
117   XR(1)=1000.0                                                       INTC3750
      XR(2)=1000.0                                                       INTC3760
114   RETURN                                                             INTC3770
      END                                                                INTC3780
      SUBROUTINE INTPLT(X,Y,Z,XG,YG,NX,NY,ZRES)                          INTC3790
C LINEAR INTERPOLATION ON CALIBRATION SURFACE TO EVALUATE                INTC3800
C CP VALUE AT CO-ORDINATES XG,YG. THE RESULT RETURNED IS ZRES            INTC3810
      DIMENSION X(40),Y(40),Z(40,40)                                     INTC3820
C SEARCH FOR I OF LEFT X LINE                                            INTC3830
      DO 1 IC=1,NX                                                       INTC3840
      IF(X(IC).GE.XG) GO TO 2                                            INTC3850
1     CONTINUE                                                           INTC3860
2     I=IC-1                                                             INTC3870
C SEARCH FOR J OF LOWER Y LINE                                           INTC3880
      DO 3 JC=1,NY                                                       INTC3890
      IF(Y(JC).GE.YG) GO TO 4                                            INTC3900
3     CONTINUE                                                           INTC3910
4     J=JC-1                                                             INTC3920
      AL=(Y(J+1)-Y(J))/(X(I+1)-X(I))                                     INTC3930
      BL=Y(J)-AL*X(I)                                                    INTC3940
      YCR=(AL*XG)+BL                                                     INTC3950
      IF(YG.EQ.YCR) GO TO 7                                              INTC3960
      IF(YG.GT.YCR) GO TO 5                                              INTC3970
C RESULTING Z IS IN LOWRER TRIANGLE                                      INTC3980
      X3=X(I+1)                                                          INTC3990
      Y3=Y(J)                                                            INTC4000
      Z3=Z(I+1,J)                                                        INTC4010
      GO TO 6                                                            INTC4020
C RESULTING Z IS IN UPPER TRIANGLE                                       INTC4030
5     X3=X(I)                                                            INTC4040
      Y3=Y(J+1)                                                          INTC4050
      Z3=Z(I,J+1)                                                        INTC4060
C GENERAL CALCULATION:GOOD FOR BOTH TRIANGLES                            INTC4070
6     X1=X(I)                                                            INTC4080
      Y1=Y(J)                                                            INTC4090
      Z1=Z(I,J)                                                          INTC4100
      X2=X(I+1)                                                          INTC4110
      Y2=Y(J+1)                                                          INTC4120
      Z2=Z(I+1,J+1)                                                      INTC4130
      AP=((Z1-Z2)*(Y1-Y2)-(Z1-Z2)*(Y1-Y3))/((X1-X3)*(Y1-Y2)-(X1-X2)      INTC4140
     1*(Y1-Y3))                                                          INTC4150
      BP=((Z1-Z2)-AP*(X1-X2))/(Y1-Y2)                                    INTC4160
      CP=Z1-AP*X1-BP*Y1                                                  INTC4170
      ZRES=AP*XG+BP*YG+CP                                                INTC4180
      GO TO 100                                                          INTC4190
C RESULTING Z IS ON DIVIDING LINE                                        INTC4200
```

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FILE: SMVDR    FORTRAN P1 .                    N     P              S

7     ZRES=(Z(I+1,J+1)-Z(I,J))*(XG-X(I))/(X(I+1)-X(I))+Z(I,J)                  INTC4210
100   RETURN                                                                   INTC4220
      END                                                                      INTC4230
      SUBROUTINE MAXARY(Z,ZMAX,NX,NY)                                          INTC4240
C EVALUATION OF MAXIMUM OF OF CALIBRATION SURFACE MATRIX                       INTC4250
      DIMENSION Z(40,40)                                                       INTC4260
      DO 1 I=1,NX                                                              INTC4270
      DO 1 J=1,NY                                                              INTC4280
1     IF(Z(I,J).GE.ZMAX) ZMAX=Z(I,J)                                           INTC4290
      RETURN                                                                   INTC4300
      END                                                                      INTC4310
      SUBROUTINE MINARY(Z,ZMIN,NX,NY)                                          INTC4320
C EVALUATION OF MINIMUM OF OF CALIBRATION SURFACE MATRIX                       INTC4330
      DIMENSION Z(40,40)                                                       INTC4340
      DO 1 I=1,NX                                                              INTC4350
      DO 1 J=1,NY                                                              INTC4360
1     IF(Z(I,J).LE.ZMIN) ZMIN=Z(I,J)                                           INTC4370
      RETURN                                                                   INTC4380
      END                                                                      INTC4390
C END OF SMVDR                                                                 INTC4400
                                                                               INTC4410
```

APPENDIX 3

LISTING OF WVDR

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  07/08/75  16.45.53

FILE: PVCR     FORTRAN  F1                    N     P              S

C START OF PVCR                                                          INT00010
      DIMENSION ALF(10),PHI(10),XA(40),YA(40),                           INT00020
     1ZA(40,40),XB(40),YB(40),ZB(40,40),XAX(40),YAX(40),                 INT00030
     2ZAX(40,40),XBX(40),YBX(40),ZBX(40,40)                              INT00040
119   FORMAT(2I)                                                         INT00050
131   FORMAT(F7.1)                                                       INT00060
130   FORMAT(F9.1)                                                       INT00070
120   FORMAT(F9.5)                                                       INT00080
132   FORMAT(F10.5)                                                      INT00090
135   FORMAT(F9.5)                                                       INT00100
136   FORMAT(F17.5)                                                      INT00110
C READ PROBE CALIBRATION DATA                                            INT00120
      READ(2,119) NX,NY                                                  INT00130
      DO 121 I=1,NX                                                      INT00140
      READ(2,130) XA(I)                                                  INT00150
121   CONTINUE                                                           INT00160
      DO 122 I=1,NY                                                      INT00170
      READ(2,130) YA(I)                                                  INT00180
122   CONTINUE                                                           INT00190
      DO 123 I=1,NX                                                      INT00200
      DO 123 J=1,NY                                                      INT00210
      READ(2,120) ZA(I,J)                                                INT00220
123   CONTINUE                                                           INT00230
      DO 221 I=1,NX                                                      INT00240
      READ(2,130) XB(I)                                                  INT00250
221   CONTINUE                                                           INT00260
      DO 222 I=1,NY                                                      INT00270
      READ(2,130) YB(I)                                                  INT00280
222   CONTINUE                                                           INT00290
      DO 223 I=1,NX                                                      INT00300
      DO 223 J=1,NY                                                      INT00310
      READ(2,120) ZB(I,J)                                                INT00320
223   CONTINUE                                                           INT00330
C TRANSFORM CALIBRATION MATRICES                                         INT00340
      DO 224 I=1,NY                                                      INT00350
224   XAX(I)=YA(I)                                                       INT00360
      DO 225 I=1,NX                                                      INT00370
225   YAX(I)=XA(I)                                                       INT00380
      DO 226 I=1,NY                                                      INT00390
      DO 226 J=1,NX                                                      INT00400
226   ZAX(I,J)=ZA(J,I)                                                   INT00410
      DO 227 I=1,NY                                                      INT00420
227   XBX(I)=YB(I)                                                       INT00430
      DO 228 I=1,NX                                                      INT00440
228   YBX(I)=XB(I)                                                       INT00450
      DO 229 I=1,NY                                                      INT00460
      DO 229 J=1,NX                                                      INT00470
229   ZBX(I,J)=ZB(J,I)                                                   INT00480
C PROBE SETTINGS                                                         INT00490
      YPA=0.0                                                            INT00500
      YPB=55.                                                            INT00510
      XPA=0.0                                                            INT00520
      XPC=20.                                                            INT00530
      XPD=-20.                                                           INT00540
C PROGRAM CONSTANTS                                                      INT00550
      YRLC=-30.                                                          INT00560
      YRLP=30.                                                           INT00570
      YRIN=-30.                                                          INT00580
      XRLC=-30.                                                          INT00590
      XRLP=30.                                                           INT00600
      XRIN=-30.                                                          INT00610
      ICOPS=1                                                            INT00620
      NOSURS=2                                                           INT00630
      NOSIM=1                                                            INT00640
      IIT=1                                                              INT00650
      ISCAN=1                                                            INT00660
      RELAPS=0.2                                                         INT00670
C EXPERIMENT SIMULATION                                                  INT00680
19    CONTINUE                                                           INT00690
401   FORMAT(F15.4)                                                      INT00700
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FILE: AVOR     FORTRAN P1 .                    N     P              S

      READ(5,401) PT                                                    INTC0710
      WRITE(6,401) PT                                                   INTC0720
      IF(NCSIM.EQ.2) GO TO 500                                          INTC0730
      READ(5,401) PS                                                    INTC0740
      WRITE(6,401) PS                                                   INTC0750
      READ(5,401) ALFA                                                  INTC0760
      WRITE(6,401) ALFA                                                 INTC0770
      READ(5,401) PHII                                                  INTC0780
      WRITE(6,401) PHII                                                 INTC0790
      CALL INTPLT(XA,YA,ZA,ALFA,PHII,NX,NY,CPA)                         INTC0800
      ALFC=ALFA-XPC                                                     INTC0810
      CALL INTPLT(XA,YA,ZA,ALFC,PHII,NX,NY,CPC)                         INTC0820
      ALFD=ALFA-XPD                                                     INTC0830
      CALL INTPLT(XA,YA,ZA,ALFD,PHII,NX,NY,CPD)                         INTC0840
      PHIB=PHII-YPB                                                     INTC0850
      CALL INTPLT(XB,YB,ZB,ALFA,PHIB,NX,NY,CPB)                         INTC0860
      WRITE(6,402) CPA,CPB,CPC,CPD                                      INTC0870
402   FORMAT(' TRUE CPS',4F10.5)                                        INTC0880
      PDYN=PT-PS                                                        INTC0890
      PPA=CPA*PDYN+PS                                                   INTC0900
      PPB=CPB*PDYN+PS                                                   INTC0910
      PPC=CPC*PDYN+PS                                                   INTC0920
      PPD=CPD*PDYN+PS                                                   INTC0930
      WRITE(6,403) PPA,PPB,PPC,PPD                                      INTC0940
403   FORMAT(' SIMUL PRS',4F10.2)                                       INTC0950
C READ MEASUREMENTS DATA                                                INTC0960
      IF(NCSIM.EQ.1) GO TO 501                                          INTC0970
500   READ(5,135) PPA                                                   INTC0980
      WRITE(6,136) PPA                                                  INTC0990
      READ(5,135) PPB                                                   INTC1000
      WRITE(6,136) PPB                                                  INTC1010
      READ(5,135) PPC                                                   INTC1020
      WRITE(6,136) PPC                                                  INTC1030
      READ(5,135) PPD                                                   INTC1040
      WRITE(6,136) PPD                                                  INTC1050
501   READ(5,135) PSIN                                                  INTC1060
      WRITE(6,136) PSIN                                                 INTC1070
      IF(ISCAN.EQ.1) GO TO 181                                          INTC1080
180   IF(ISCAN.GT.1000) GO TO 305                                       INTC1090
      IIT=1                                                             INTC1100
      ICOPS=1                                                           INTC1110
      ISCAN=ISCAN+1                                                     INTC1120
      PSIN=PSIN+5.0                                                     INTC1130
      WRITE(6,136) PSIN                                                 INTC1140
181   CONTINUE                                                          INTC1150
      PS=PSIN                                                           INTC1160
      PSC=PS                                                            INTC1170
      PST=PS                                                            INTC1180
C CALCULATES PRESSURE COEFFICIENTS                                      INTC1190
300   CONTINUE                                                          INTC1200
      WRITE(6,940) IIT                                                  INTC1210
940   FORMAT('0',' ITERATION NO. ',I5)                                  INTC1220
      PDYN=PT-PS                                                        INTC1230
      CPA=(PPA-PS)/PDYN                                                 INTC1240
      CPB=(PPB-PS)/PDYN                                                 INTC1250
      CPC=(PPC-PS)/PDYN                                                 INTC1260
      CPD=(PPD-PS)/PDYN                                                 INTC1270
908   WRITE(6,912) CPA,CPB,CPC,CPD                                      INTC1280
912   FORMAT(' CALC CPS',4F10.5)                                        INTC1290
C CORRECTS PS ASSUMPTION TO ENSURE CP ARE IN CALIBRATION RANGE          INTC1300
      IF(NCCPS.EQ.2) GO TO 501                                          INTC1310
      ZAMAX=-10000.                                                     INTC1320
      CALL MAXIM(ZA,ZAMAX,NX,NY)                                        INTC1330
      IF(CPA.GT.ZAMAX) PSC=1.01*PS                                      INTC1340
      IF(CPC.GT.ZAMAX) PSC=1.01*PS                                      INTC1350
      IF(CPD.GT.ZAMAX) PSC=1.01*PS                                      INTC1360
      ZBMAX=-10000.                                                     INTC1370
      CALL MAXIM(ZB,ZBMAX,NX,NY)                                        INTC1380
      IF(CPB.GT.ZBMAX) PSC=1.01*PS                                      INTC1390
      ZAMIN=10000.                                                      INTC1400
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FILE: WVCR     FORTRAN  P1                    N     P              S

      CALL MINARY(ZA,ZAMIN,NX,NY)                                          INTC1410
      IF(CPA.LT.ZAMIN) PSC=0.99*PS                                         INTC1420
      IF(CPC.LT.ZAMIN) PSC=0.99*PS                                         INTC1430
      IF(CPD.LT.ZAMIN) PSC=0.99*PS                                         INTC1440
      ZBMIN=10000.                                                         INTC1450
      CALL MINARY(ZB,ZBMIN,NX,NY)                                          INTC1460
      IF(CPB.LT.ZBMIN) PSC=0.99*PS                                         INTC1470
      IF(PSC.EQ.PST) GO TO 301                                             INTC1480
      ICCPS=ICCPS+1                                                        INTC1490
963   WRITE(6,964) ICCPS                                                   INTC1500
964   FORMAT(' ICCPS AS' ,I5)                                              INTC1510
      IF(ICCPS.GT.10) GO TO 180                                            INTC1520
      PS=PSC                                                               INTC1530
      PST=PSC                                                              INTC1540
920   WRITE(6,921) PSC                                                     INTC1550
921   FORMAT(' PSC IS    ',F20.5)                                          INTC1560
      GO TO 300                                                            INTC1570
301   CONTINUE                                                             INTC1580
C CALCULATES TWO ALF & PHI ANGLES FOR 'I' & 'II'                           INTC1590
      CALL INTSCS(XPA,YPA,YRLO,YRUP,YRIN,                                  INTC1600
     1CPA,CPB,ALF,PHI,XA,YA,ZA,                                            INTC1610
     2XB,YB,ZB,XAX,YAX,ZAX,XBX,YBX,ZBX,NX,NY)                              INTC1620
      ALF1=ALF(1)                                                          INTC1630
      ALF2=ALF(2)                                                          INTC1640
      PHI1=PHI(1)                                                          INTC1650
      PHI2=PHI(2)                                                          INTC1660
C CALCULATES TWO ALF & PHI ANGLES FOR 'I' & 'III'                          INTC1670
      CALL INTSCS(XPA,XPC,XRLO,XRUP,XRIN,                                  INTC1680
     1CPA,CPC,PHI,ALF,XAX,YAX,ZAX,                                         INTC1690
     2XAX,YAX,ZAX,XA,YA,ZA,XA,YA,ZA,NY,NX)                                 INTC1700
      ALF3=ALF(1)                                                          INTC1710
      ALF4=ALF(2)                                                          INTC1720
      PHI3=PHI(1)                                                          INTC1730
      PHI4=PHI(2)                                                          INTC1740
C SELECTS THE PROPER ALF & PHI ANGLES OUT OF THE FOUR VALUES               INTC1750
      FALF=((ALF1+ALF2+ALF3+ALF4)-AMAX1(ALF1,ALF2,ALF3,                    INTC1760
     1ALF4)-AMIN1(ALF1,ALF2,ALF3,ALF4))/2                                  INTC1770
      FPHI=((PHI1+PHI2+PHI3+PHI4)-AMAX1(PHI1,PHI2,PHI3,PHI4)               INTC1780
     1-AMIN1(PHI1,PHI2,PHI3,PHI4))/2                                       INTC1790
900   WRITE(6,901)FALF,FPHI                                                INTC1800
901   FORMAT(' SELECTED',2F10.2)                                           INTC1810
C CALCULATES NEW PS FROM DATA OF POSITION D AND CORRECTS PT                INTC1820
      ALFDN=FALF-XPD                                                       INTC1830
      CALL INTFLT(XA,YA,ZA,ALFDN,FPHI,NX,NY,CPD)                           INTC1840
      ALFCN=FALF-XPC                                                       INTC1850
      CALL INTFLT(XA,YA,ZA,ALFCN,FPHI,NX,NY,CPC)                           INTC1860
905   WRITE(6,910) CPC,CPD                                                 INTC1870
910   FORMAT(' NEW CPC & CPD CALLED',2F15.5)                               INTC1880
      PSN=(PPC*CPD-PPD*CPC)/(CPD-CPC)                                      INTC1890
907   WRITE(6,911) FALF,FPHI,PST,PT                                        INTC1900
911   FORMAT(' ITERATION VALUES',2F6.2,2F10.2)                             INTC1910
C CONVERGENCE TESTS                                                        INTC1920
950   DELPS=PSN-PS                                                         INTC1930
951   WRITE(6,952) PS,PSN,DELPS                                            INTC1940
952   FORMAT(' EPSPS VALUES',3F15.5)                                       INTC1950
      EPSPS=ABS((PSN-PS)/PS)                                               INTC1960
960   WRITE(6,961) EPSPS                                                   INTC1970
961   FORMAT(' EPSPS IS' ,F25.15)                                          INTC1980
      EPSPSG=.0000000C099*(PT**2.0)-.00000098*PT                           INTC1990
      IF(IEPS1.EQ.2) EPSPSG=.0C000000009*(PT**2.0)-.0000008*PT             INTC2000
      IF(IEPS2.EQ.2) EPSPSG=.000000C009*(PT**2.0)-.000008E*PT              INTC2010
      IF(EPSPS.GT.EPSPSG) GO TO 310                                        INTC2020
      GO TO 303                                                            INTC2030
310   CONTINUE                                                             INTC2040
      III=III+1                                                            INTC2050
      IF(III.GT.10) GO TO 305                                              INTC2060
      PS=PS+RELAPS*(PSN-PS)                                                INTC2070
      PSC=PS                                                               INTC2080
      PST=PS                                                               INTC2090
924   WRITE(6,925) PS                                                      INTC2100
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FILE: WVOP     FORTRAN  P1                    N     P              S

525   FORMAT(' CURR PS IS ',F15.5)                                          INTC2110
      GO TO 300                                                             INTC2120
303   WRITE(6,171) FALF,FPM1,PSM,PT                                         INTC2130
171   FORMAT(3F15.2,F15.3)                                                  INTC2140
      GO TO 195                                                             INTC2150
305   WRITE(6,307)                                                          INTC2160
307   FORMAT(' SCANNED 100 TIMES')                                          INTC2170
      GO TO 195                                                             INTC2180
      END                                                                   INTC2190
      SUBROUTINE INTSCS(ARP1,ARP2,ARLO,ARUP,ARIN,                           INTC2200
     1HT1,HT2,RES1,RES2,X1,Y1,Z1,                                           INTC2210
     2X2,Y2,Z2,X3,Y3,Z3,X4,Y4,Z4,N1,N2)                                     INTC2220
      DIMENSION RES1(10),RES2(10),ARRES(10),X1(40),Y1(40),                  INTC2230
     1Z1(40,40),X2(40),Y2(40),Z2(40,40),X3(40),Y3(40),                      INTC2240
     2Z3(40,40),X4(40),Y4(40),Z4(40,40)                                     INTC2250
      RES1(1)=9000.                                                         INTC2260
      RES1(2)=9000.                                                         INTC2270
      RES2(1)=9000.                                                         INTC2280
      RES2(2)=9000.                                                         INTC2290
      ISL=1                                                                 INTC2300
      ISR=1                                                                 INTC2310
      DAR=1.                                                                INTC2320
      AR2R=ARIN                                                             INTC2330
      GO TO 152                                                             INTC2340
150   AR2R=AR2R+DAR                                                         INTC2350
      AR2RJ=AR2R                                                            INTC2360
152   ARM1=AR2R-ARP1                                                        INTC2370
      ARM2=AR2R-ARP2                                                        INTC2380
C CHECK FOR LOWER CALIBRATION RANGE                                         INTC2390
      IF(ARM1.LT.ARLO) GO TO 150                                            INTC2400
      IF(ARM2.LT.ARLO) GO TO 150                                            INTC2410
      K=1                                                                   INTC2420
C CALCULATES INITIAL PENETRATION POINTS                                     INTC2430
      CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                            INTC2440
      RAJL=ARRES(1)                                                         INTC2450
      RAJR=ARRES(2)                                                         INTC2460
      CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,ARM2,ARRES)                            INTC2470
      RBJL=ARRES(1)                                                         INTC2480
      RBJR=ARRES(2)                                                         INTC2490
C CALCULATES SUCCESIVE PENETRATION POINTS                                   INTC2500
      DO 140 I=1,10000                                                      INTC2510
      AR2R=AR2R+DAR                                                         INTC2520
      ARM1=AR2R-ARP1                                                        INTC2530
      ARM2=AR2R-ARP2                                                        INTC2540
C CHECK FOR UPPER CALIBRATION RANGE                                         INTC2550
      IF(ARM1.GT.ARUP) GO TO 195                                            INTC2560
      IF(ARM2.GT.ARUP) GO TO 195                                            INTC2570
      CALL PENPTS(N1,N2,X1,Y1,Z1,HT1,ARM1,ARRES)                            INTC2580
      RAIL=ARRES(1)                                                         INTC2590
      RAIR=ARRES(2)                                                         INTC2600
      CALL PENPTS(N1,N2,X2,Y2,Z2,HT2,AR42,ARRES)                            INTC2610
      RBIL=ARRES(1)                                                         INTC2620
      RBIR=ARRES(2)                                                         INTC2630
      IF(RAJL.EQ.1000.) ISL=10                                              INTC2640
      IF(REJL.EQ.1000.) ISL=10                                              INTC2650
      IF(RBJR.EQ.1000.) ISR=10                                              INTC2660
      IF(RAJR.EQ.1000.) ISR=10                                              INTC2670
      IF(RAIL.EQ.1000.) ISL=10                                              INTC2680
      IF(RBIL.EQ.1000.) ISL=10                                              INTC2690
      IF(RBIR.EQ.1000.) ISR=10                                              INTC2700
      IF(RAIR.EQ.1000.) ISR=10                                              INTC2710
C CHECK FOR DIRECT HIT ON LEFT INTERSECTION,EVALUATE IF REQUIRED             INTC2720
      IF(ISL.NE.10) GO TO 164                                               INTC2730
      ISL=1                                                                 INTC2740
      GO TO 183                                                             INTC2750
164   IF(RAIL.NE.RBIL) GO TO 180                                            INTC2760
      RES1(K)=RAIL                                                          INTC2770
      RES2(K)=AR2R                                                          INTC2780
      IF(K.EQ.2) GO TO 155                                                  INTC2790
      K=2                                                                   INTC2800
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FILE: WVDR     FORTRAN  P1                    N     P              S
      GO TO 184                                                          INTC2810
C CHECK FOR INTERMEDIATE LEFT INTERSECTION,EVALUATE IF REQUIRED          INTC2820
180   IF(ISL.NE.10) GO TO 160                                            INTC2830
      ISL=1                                                              INTC2840
      GO TO 183                                                          INTC2850
160   IF((RAJL-RBJL)/(RAIL-RBIL).GT.0.0) GO TO 183                       INTC2860
      AA=(AR2RJ-AR2R)/(RAJL-RAIL)                                        INTC2870
      BA=AR2R-AA*RAIL                                                    INTC2880
      AB=(AR2RJ-AR2R)/(RBJL-RBIL)                                        INTC2890
      BB=AR2R-AB*RBIL                                                    INTC2900
      RES1(K)=(BB-BA)/(AA-AB)                                            INTC2910
      RES2(K)=AA*RES1(K)+BA                                              INTC2920
      IF(K.EQ.2) GO TO 155                                               INTC2930
      K=2                                                                INTC2940
C CHECK FOR DIRECT HIT ON RIGHT INTERSECTION,EVALUATE IF REQUIRED        INTC2950
183   IF(ISR.NE.10) GO TO 161                                            INTC2960
      ISR=1                                                              INTC2970
      GO TO 163                                                          INTC2980
161   IF(RAIR.NE.RBIR) GO TO 182                                         INTC2990
      RES1(K)=RBIR                                                       INTC3000
      RES2(K)=AR2R                                                       INTC3010
      IF(K.EQ.2) GO TO 155                                               INTC3020
      K=2                                                                INTC3030
      GO TO 163                                                          INTC3040
C CHECK FOR INTERMEDIATE RIGHT INTERSECTION,EVALUATE IF REQUIRED         INTC3050
182   IF(ISR.NE.10) GO TO 162                                            INTC3060
      ISR=1                                                              INTC3070
      GO TO 183                                                          INTC3080
162   IF((RAJR-RBJR)/(RAIR-RBIR).GT.0.0) GO TO 165                       INTC3090
      AA=(AR2RJ-AR2R)/(RAJR-RAIR)                                        INTC3100
      BA=AR2R-AA*RAIR                                                    INTC3110
      AB=(AR2RJ-AR2R)/(RBJR-RBIR)                                        INTC3120
      BB=AR2R-AB*RBIR                                                    INTC3130
      RES1(K)=(BB-BA)/(AA-AB)                                            INTC3140
      RES2(K)=AA*RES1(K)+BA                                              INTC3150
      IF(K.EQ.2) GO TO 155                                               INTC3160
      K=2                                                                INTC3170
C RE-INITIATE                                                            INTC3180
163   AR2RJ=AR2R                                                         INTC3190
      RAJL=RAIL                                                          INTC3200
      RAJR=RAIR                                                          INTC3210
      RBJL=RBIL                                                          INTC3220
      RBJR=RBIR                                                          INTC3230
140   CONTINUE                                                           INTC3240
      WRITE(6,210)                                                       INTC3250
210   FORMAT(' LOOP 140 THROUGH,TO POINTS FOUND')                        INTC3260
      GO TO 155                                                          INTC3270
195   IF(RES1(1).EQ.9000.0) GO TO 191                                    INTC3280
      IF(RES1(2).EQ.9000.0) GO TO 191                                    INTC3290
      IF(RES2(1).EQ.9000.0) GO TO 191                                    INTC3300
      IF(RES2(2).EQ.9000.0) GO TO 191                                    INTC3310
      GO TO 155                                                          INTC3320
C EVALUATION OF INTERSECTIONS WHEN CURVES ARE ALMOST TANGENT             INTC3330
191   YGC=0.0                                                            INTC3340
      CALL PENPTS(N2,N1,X3,Y3,Z3,HT1,YGC,ARRES)                          INTC3350
      R1=ABS(ARRES(2)-ARRES(1))/2                                        INTC3360
      CALL PENPTS(N2,N1,X4,Y4,Z4,HT2,YGC,ARRES)                          INTC3370
      R2=ABS(ARRES(2)-ARRES(1))/2                                        INTC3380
      RES2(1)=((R1**2)-(R2**2)+(ARP2**2))/(2.0*ARP2)                     INTC3390
      RES2(2)=RES2(1)                                                    INTC3400
      RES1(1)=SQRT(ABS((R1**2)-(RES2(1)**2)))                            INTC3410
      RES1(2)=-RES1(1)                                                   INTC3420
155   RETURN                                                             INTC3430
      END                                                                INTC3440
      SUBROUTINE PENPTS(NX,NY,X,Y,Z,HT,YG,XR)                            INTC3450
      DIMENSION Y(40),Z(40),Z(40,40),X(40),XR(10)                        INTC3460
      IR=1                                                               INTC3470
C SEARCH FOR J OF LOWER Y LINE                                           INTC3480
      DO 101 I=1,NY                                                      INTC3490
      IF (Y(I).GE.YG) GO TO 102                                          INTC3500
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FILE: WVDR     FORTRAN P1                    N     P              S
101   CONTINUE                                                          INT03510
102   J=I-1                                                             INT03520
C COARSE SCAN FOR ZERO PASS                                             INT03530
C NEXT 4 LINES ARE EXECUTED IN FIRST SEARCH ONLY                        INT03540
      YC=(YG-Y(J))/(Y(J+1)-Y(J))                                        INT03550
      ZX(I)=(Z(I,J+1)-Z(I,J))*YC+Z(I,J)                                 INT03560
      IF(ZX(I).EQ.HT) GO TO 107                                         INT03570
      IB=2                                                              INT03580
112   DO 103 I=IB,NX                                                    INT03590
      ZX(I)=(Z(I,J+1)-Z(I,J))*YC+Z(I,J)                                 INT03600
      ZM=(Z(I,J+1)-Z(I-1,J))*(YG-Y(J))/(Y(J+1)-Y(J))+Z(I-1,J)           INT03610
      IF(ZX(I).EQ.HT) GO TO 104                                         INT03620
      IF((ZX(I-1)-HT)/(ZX(I)-HT).LT.0.0) GO TO 104                      INT03630
103   CONTINUE                                                          INT03640
      GO TO 116                                                         INT03650
C CALCULATION OF PENETRATIONS IN EITHER TRIANGLE                        INT03660
104   XM=X(I-1)+(X(I)-X(I-1))*(YG-Y(J))/(Y(J+1)-Y(J))                   INT03670
      IF(ZM.EQ.HT) GO TO 105                                            INT03680
      IF((ZX(I)-HT)/(ZM-HT).LT.0.0) GO TO 105                           INT03690
      DD=ABS(HT-ZM)+ABS(ZX(I-1)-HT)                                     INT03700
      XS=X(I-1)+(XM-X(I-1))*ABS(ZX(I-1)-HT)/DD                          INT03710
      GO TO 110                                                         INT03720
105   XS=XM+(X(I)-XM)*ABS(ZM-HT)/(ABS(ZM-HT)+ABS(ZX(I)-HT))             INT03730
      GO TO 110                                                         INT03740
C LOGICAL PENETRATIONS ACCUMULATION                                     INT03750
107   XR(1)=X(I)                                                        INT03760
      I=1                                                               INT03770
      GO TO 113                                                         INT03780
108   XR(IR)=X(I)                                                       INT03790
      GO TO 111                                                         INT03800
110   XR(IR)=XS                                                         INT03810
111   IF(IR.EQ.2) GO TO 114                                             INT03820
113   IR=2                                                              INT03830
      IB=I+1                                                            INT03840
      GO TO 112                                                         INT03850
116   IF(IR.EQ.1) GO TO 117                                             INT03860
      XR(2)=1000.0                                                      INT03870
      GO TO 114                                                         INT03880
117   XR(1)=1000.0                                                      INT03890
      XR(2)=1000.0                                                      INT03900
114   RETURN                                                            INT03910
      END                                                               INT03920
      SUBROUTINE INTPLT(X,Y,Z,XG,YG,NX,NY,ZRES)                         INT03930
C LINEAR INTERPOLATION OF CALIBRATION SURFACE TO EVALUATE               INT03940
C CP VALUE AT CO-ORDINATES XG,YG. THE RESULT RETURNED IS ZRES           INT03950
      DIMENSION X(40),Y(40),Z(40,40)                                    INT03960
C SEARCH FOR I OF LEFT X LINE                                           INT03970
      DO 1 IC=1,NX                                                      INT03980
      IF(X(IC).GE.XG) GO TO 2                                           INT03990
1     CONTINUE                                                          INT04000
2     I=IC-1                                                            INT04010
C SEARCH FOR J OF LOWER Y LINE                                          INT04020
      DO 3 JC=1,NY                                                      INT04030
      IF(Y(JC).GE.YG) GO TO 4                                           INT04040
3     CONTINUE                                                          INT04050
4     J=JC-1                                                            INT04060
      AL=(Y(J+1)-Y(J))/(X(I+1)-X(I))                                    INT04070
      BL=Y(J)-AL*X(I)                                                   INT04080
      YCR=(AL*XG)+BL                                                    INT04090
      IF(YG.EQ.YCR) GO TO 7                                             INT04100
      IF(YG.LT.YCR) GO TO 5                                             INT04110
C RESULTING Z IS IN LOWER TRIANGLE                                      INT04120
      X3=X(I+1)                                                         INT04130
      Y3=Y(J)                                                           INT04140
      Z3=Z(I+1,J)                                                       INT04150
      GO TO 6                                                           INT04160
C RESULTING Z IS IN UPPER TRIANGLE                                      INT04170
5     X3=X(I)                                                           INT04180
      Y3=Y(J+1)                                                         INT04190
      Z3=Z(I,J+1)                                                       INT04200
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FILE: WVDR     FORTRAN  P1                    N     P           S
C GENERAL CALCULATION:GOOD FOR BOTH TRIANGLES                                  INTC4210
6       X1=X(I)                                                                INTC4220
        Y1=Y(J)                                                                INTC4230
        Z1=Z(I,J)                                                              INTC4240
        X2=X(I+1)                                                              INTC4250
        Y2=Y(J+1)                                                              INTC4260
        Z2=Z(I+1,J+1)                                                          INTC4270
        AP=((Z1-Z3)*(Y1-Y2)-(Z1-Z2)*(Y1-Y3))/((X1-X3)*(Y1-Y2)-(X1-X2)          INTC4280
       1*(Y1-Y3))                                                              INTC4290
        BP=((Z1-Z2)-AP*(X1-X2))/(Y1-Y2)                                        INTC4300
        CP=Z1-AP*X1-BP*Y1                                                      INTC4310
        ZRES=AP*XG+BP*YG+CP                                                    INTC4320
        GO TO 100                                                              INTC4330
C RESULTING Z IS ON DIVIDING LINE                                              INTC4340
7       ZRES=(Z(I+1,J+1)-Z(I,J))*(XG-X(I))/(X(I+1)-X(I))+Z(I,J)                INTC4350
100     RETURN                                                                 INTC4360
        END                                                                    INTC4370
        SUBROUTINE MAXARY(Z,ZMAX,NX,NY)                                        INTC4380
C EVALUATION OF MAXIMUM OF OF CALIBRATION SURFACE MATRIX                       INTC4390
        DIMENSION Z(40,40)                                                     INTC4400
        DO 1 I=1,NX                                                            INTC4410
        DO 1 J=1,NY                                                            INTC4420
1       IF(Z(I,J).GE.ZMAX) ZMAX=Z(I,J)                                         INTC4430
        RETURN                                                                 INTC4440
        END                                                                    INTC4450
        SUBROUTINE MINARY(Z,ZMIN,NX,NY)                                        INTC4460
C EVALUATION OF MINIMUM OF OF CALIBRATION SURFACE MATRIX                       INTC4470
        DIMENSION Z(40,40)                                                     INTC4480
        DO 1 I=1,NX                                                            INTC4490
        DO 1 J=1,NY                                                            INTC4500
1       IF(Z(I,J).LE.ZMIN) ZMIN=Z(I,J)                                         INTC4510
        RETURN                                                                 INTC4520
        END                                                                    INTC4530
C END OF WVDR                                                                  INTC4540
                                                                               INTC4550
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